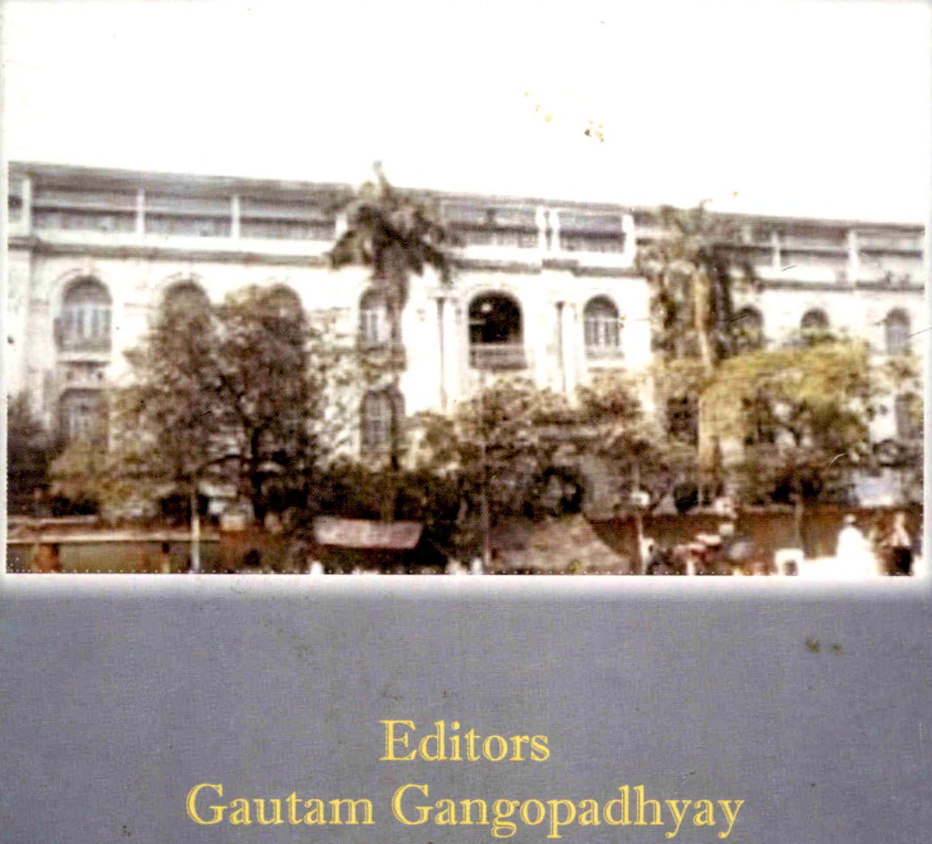
# CU PHYSICS 100

## DEPARTMENT OF PHYSICS
## UNIVERSITY OF CALCUTTA
## 1916 – 2015



Editors
Gautam Gangopadhyay
Anirban Kundu

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# From The Editors

The Department of Physics, University of Calcutta, is celebrating its centenary during the year 2016. The first Professorships of Physics were offered by the University under the endowments of two of the eminent lawyers of the Calcutta Bar, Sir Taraknath Palit and Sir Rashbehary Ghose. In two separate meetings of the Management Boards of these two endowments, both held on January 24, 1914, and both presided by Sir Asutosh Mookerjee, the Palit Professorship was offered to C.V. Raman and the Ghose Professorship to D.M. Bose. As per the rules of the Ghose trust, Bose went to Berlin for further studies, and came back in 1919. The syndicate records show that "Mr. C.V. Raman. M.A., joined his post as Palit Professor of Physics on the afternoon of July 2, 1917". Before Raman, two Lecturers joined this department as the first teachers: Jogeschandra Mukherjee and Phanindranath Ghosh. Within a few years, a number of top-ranking physicists, like Meghnad Saha, Satyendranath Bose, and Sisirkumar Mitra also joined the Department as teachers. The Department started to carve out its glorious path in the development of Indian science.

Not all of them stayed: Raman left in 1933 to become the Director of IISc, Saha relinquished his post as Khaira professor of Physics to move to Allahabad in 1923 and then again came back as the Palit Professor in 1938, S.N. Bose moved to Dacca (now Dhaka) University in 1921 and came back in 1945, D.M. Bose took charge of the neighbouring Bose Institute in 1938, Mitra established a separate department of Radiophysics, Ghosh started the Applied Physics department. The standard of teaching and research varied over time, but there were always some motivating teachers. The Institute of Nuclear Physics was established as a part of the Department, and later moved out to be a separate Institute, named after Saha following his death, but always maintained a very close contact with the Department.

The quality of teaching, even in those early days, can be guessed by the papers set in the final examinations. In 1920, we see questions on General Relativity, within six years of its birth, at a time when no American and very few European universities would have dared to set such questions. Same comments apply for questions on Quantum Mechanics set in early 1930s. These questions are freely available in the University of Calcutta website; interested readers may explore these gems. Some are available in this volume.

The Department still plays a very important role in physics teaching and research in India. There is hardly a top-ranking Indian institute where its alumni are not to be found. Several of our alumni are there in institutes abroad. During the last twenty years, six of our alumni received the highest award in Indian science, the Bhatnagar award.

In this volume, we have tried to look back at the past, sometimes glorious, sometimes not so glorious, but always interesting and intriguing. The history of the Department is much more than the individual sum of its faculty members. The reader will find articles ranging from the big names of science to the history of the Department and its close neighbours, and the science education in British India as a whole. Some forgotten personalities have also been brought to light. We would like to thank all the contributors for their efforts. We rushed them for their articles and they never complained but always tried to accommodate us. The lacunae, none more visible than the amateur attempt of compiling the initial history of the Department from the CU records, are completely our responsibility.

We would like to sincerely thank our former Vice-Chancellor, Professor Suranjan Das, a noted historian by himself, who took a keen interest in this volume. and arranged to publish it through the Calcutta University Press, and also the University Librarian, Dr. Soumitra Sarkar, for digitising and archiving the old records of the university from which we have heavily drawn. We also thank the staff members of the CU Press for bringing out the volume in time, and Ms. Bela Mondal for her help in compiling the Syndicate records for the first twenty years of the Department. Thanks are also due to Professor Arnab Rai Choudhury of IISc and Mr. Vivek Bald for providing the soft copy of the autobiography of Sailendranath Ghose, to the Indian Academy of Sciences for permitting us to reprint the article by Purnima Sinha, to the Niels Bohr archive for permitting us to reprint two rare photographs of Bidhubhushan Ray, and to Mr. Sunish Deb for providing a photograph of C.K. Majumdar. Without the active help of our departmental colleagues, in particular Parongama Sen, Subinay Dasgupta, and Amitava Raychaudhuri, and our graduate students, like Kartick Malik who took a number of photographs used here, this volume would not have been possible.

Comments and suggestions are most welcome; they may be sent to any of us, or preferably to cu.physics100@gmail.com.

Gautam Gangopadhyay
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# The Golden Age of Calcutta Physics: Difficulties in Reconstructing the History

**Arnab Rai Choudhuri***
Department of Physics, Indian Institute of Science, Bangalore–560012, India

*Classes started in the newly established Physics Department of Calcutta University Science College in 1916. Raman, Bose and Saha were three young members of the small physics faculty consisting of barely half a dozen faculty members. Within about one decade, three extraordinary discoveries came from these young men – Saha ionization equation in 1920, Bose statistics in 1924, Raman effect in 1928. However, fortunes of Calcutta University quickly got intertwined with India's freedom struggle led by Mahatma Gandhi exactly at the same time and the physics group got tragically disrupted. Indian physics never succeeded in reaching that height again. This paper discusses the difficulties in reconstructing a critical history of this Calcutta school of physics during the very short epoch of unmatched brilliance.*

## 1. A Look at an Extraordinary Epoch

We live in an age obsessed with ranking everything: from cinemas to washing machines, from tennis players to universities. Although India has one of the fastest growing economies in the world and is striving to find her place within the nations of the world, India's ranking remains poor in several important spheres of human activity. Apart from the poor showing in the Olympic games, one other area in which India's dismal record has become a huge embarrassment to India's intellectual class is the ranking of universities. No Indian university finds a place within the world's top 100.

Just about a century ago, for about one remarkable decade, an Indian university reached a height which no Indian university afterwards succeeded in reaching. It was Calcutta University under the leadership of the visionary Vice-Chancellor Sir Asutosh Mookerjee. That was a time when the world ranking of universities had not yet begun and we do not know what the rank of Calcutta University at that time would have been. However, judged by any reasonable yardstick, Calcutta University surely would have ranked among the world's greatest for a brief period of unmatched brilliance. Although Mookerjee managed to attract outstanding faculty in as diverse fields as philosophy, history and art, here we are concerned with the Physics Department of the University during the golden period. Mookerjee was a brilliant mathematician himself and, at a very young age, published a string of original papers in mathematics in leading journals, attracting international attention. As there was very little scope of a career in mathematics in India of that time, Mookerjee had to take up the legal profession before being appointed to head Calcutta University. Although Mookerjee could not pursue mathematics research in his later life, he maintained a lifelong interest in mathematics and physics. When Mookerjee took over the reins of Calcutta University, universities in India were primarily bodies for conducting examinations. Mookerjee wanted to create post-graduate departments where faculty members would carry on research. India was under the British rule and Mookerjee knew that financial support from the Government would not be forthcoming. He established the University Science College with donations from rich Indians, which enabled him to establish a few professorships.

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An account of how Mookerjee built up the Physics Department of Calcutta University at the Rajabazar Science College campus almost reads like a fairy tale. He wanted to attract faculty who would teach modern topics in physics and simultaneously carry on research. There was no tradition of physics research in India at that time, apart from solitary workers like J.C. Bose at Presidency College (who was no longer working on physics at that time after his fundamental studies of radio waves). Mookerjee started looking for young people who had the potential for growing into outstanding physicists. He knew of a 26-year-old officer in the Finance Department, who was passionate about physics and had already published about a dozen papers in top international journals by carrying on research in his spare time. Mookerjee wanted to get him for the most prestigious chair of the fledgling Physics Department—the Palit Professorship. However, Mookerjee could offer him only Rs. 1000 at the most against his possible salary of Rs. 2000. Would he be willing to take up this professorship? The young man, C.V. Raman, jumped at the offer. Mookerjee also needed younger persons to man the department. As it happened, the batch which completed master's degree in the year 1915 was an exceptional batch. Mookerjee called three bright boys of that batch for a discussion [1]. Only one of them, Sailen Ghose, was a student of physics. Although the other two, Satyendra Nath Bose and Meghnad Saha, were students of mixed mathematics (what we would now call applied mathematics), Mookerjee knew that they were interested in physics. Mookerjee asked the three boys if they could teach the modern topics of physics which had never been taught in any Indian university. Saha was assigned to teach quantum theory and Bose was assigned to teach relativity. Sailen Ghose, who was a good experimenter, was given the job of designing the laboratory course and setting up the experiments.

Before classes started in 1916, there was trouble. Although Sailen Ghose managed to acquire laboratory equipments and set up the laboratory, he could never formally join the department. He had connections with revolutionary groups fighting the British imperialism. Police found clues about this and raided his home when he was away. It appeared that he would be sent to the British penal colony of the Andaman Islands if caught. Ghose fled India in a ship bound for Philadelphia disguised as a Muslim crew member, thus putting down the curtain on what appeared to be a very promising career in physics. Ghose, however, later became a highly respected figure in the arena of international political activism. The short autobiography he wrote for the American magazine *Asia* in 1927 gives a fascinating account of the Calcutta academic world in his youth [2].

Bose and Saha were among the first to join the new Physics Department in 1916, as Palit research fellow, at the monthly salary of Rs. 200. Raman joined about a year later when he had made up his mind to quit the Finance Department. The person to whom the other named chair (Rashbehary Ghose Professorship) was offered—Debendra Mohan Bose—was in Germany when the First World War broke out. He was forced to stay there till the end of the War and could join Calcutta University only after the War ended. Raman, Bose and Saha were members of the small new Physics Department with barely half a dozen faculty members. Within about a decade, three spectacular physics discoveries emerged out of this group—Saha ionization equation in 1920, Bose statistics in 1924, Raman effect in 1928. Although Bose had shifted to Dacca University a little bit before his work on Bose statistics and, in that sense, that work should technically not be counted as a work from Calcutta University, Bose always had strong links with Calcutta University and eventually returned there again in later life. There were very few physics groups around the world – perhaps no group outside England and Germany – which could boast of three physics discoveries of this class in that decade. In many of the present-day surveys, Harvard University appears at the top. There was not even one physics discovery of this class made at Harvard University during the same period. Although the achievements of Raman, Bose and Saha dwarfed the achievements of their colleagues, it should be emphasized that some of their colleagues such as Sisir Kumar Mitra and Debendra Mohan Bose also made very important contributions to physics during the same period.

It seemed that this extraordinary decade heralded a new dawn for Indian physics. But that was not to be. That brilliant dawn quickly faded away and a fourth physics discovery of that class has not come out of India in the next 85 years! There were some obvious external reasons why academic activities of Calcutta University got derailed in a big way. Mahatma Gandhi returned to India in 1915 and the infamous Jallianwala Bagh massacre took place on 13 April 1919—exactly around the time when the fledgling Physics Department of Calcutta University was trying to find the ground under its feet. The golden age of Calcutta physics almost exactly coincided with the golden age of Indian freedom movement when the Muslim question still had not raised its ugly head and Indians were fighting together for their country. In fact, this coincidence might not be accidental. Raman, Bose and Saha have all categorically stated on various occasions that patriotic fervour was one of the driving forces behind their science. They had to prove to the world that Indians could compete with white men in science. Saha had difficulties in getting a government job in his youth because he was perceived as a sympathizer of the revolutionary groups fighting the British Empire. Raman was found weeping when he received the Nobel Prize and gave a moving account of it himself [3]: "When the Nobel award was announced I saw it as a personal triumph.... But when I sat in that crowded hall and I saw the sea of western faces surrounding me, and I, the only Indian, in my turban and closed coat, it dawned on me that I was really representing my people and my country.... Then I turned around and saw the British Union Jack under which I had been sitting and it was then that I realized that my poor country, India, did not even have a flag of her own—and it was this that triggered off my complete breakdown." Although Mookerjee always expressed the opinion that students can serve their country best by excelling in their work and was against students boycotting classes, it was an open secret that he and many professors of the University were sympathetic to the national cause. The British administration decided to punish the University for its insubordination.

All government funds to Calcutta University were drastically cut. There was a period when the University was unable to pay the salary of its faculty for several months. At the height of the crisis, in a Senate meeting on 8 December 1922 to discuss a financial offer from the government with humiliating conditions, Mookerjee spoke stirringly: "If you give me slavery in one hand and money in the other, I despise the offer... Our post-graduate teachers would starve themselves, rather than give up their freedom... I call upon you, as members of the Senate to stand up for the rights of your University... Freedom first, freedom second, freedom always: nothing else will satisfy me." In a letter dated 26 March 1923, Mookerjee turned down the offer of another term of Vice-Chancellorship with humiliating conditions. Then he suddenly died on 25 May 1924 at the age of 59. In the meeting at Calcutta University to condole his death, Lord Lytton, Viceroy of India who was also the Chancellor of Calcutta University, said [4]: "Let each of us severally resolve that this cherished creation of his life shall not suffer because he has left us... let all differences be forgotten, all mistakes forgiven, let us resolve to build over his ashes a temple of reconciliation." However, it was already too late. Although Mookerjee hoped that the "post-graduate teachers would starve themselves", many of them had already left Calcutta for greener pastures by the time of his death. Bose left for Dacca University in 1921 and Saha for Allahabad University in 1923. Calcutta University could never regain its lost glory.

Saha was abroad at the time when the financial crisis had first struck Calcutta University. Saha must have been aware of this crisis and applied for a grant to the British High Commissioner of India for his research on his return to India. The mood of the period can be gauged from the letter dated 9 February 1921 that Mookerjee wrote to Saha at that time [5]: "I wish you had applied to your Alma Mater and not to the High Commissioner. We are in great financial crisis here on account of Non-Cooperation movement, but you may rest assured that so long as it is practicable, your Alma Mater will not be slow to help you... I trust you will not hesitate to serve your Alma Mater when you return. I was deeply grieved to hear that Dr. Jnanendra Ghosh had decided to give up his Alma Mater and accept service in Dacca University. When will the children of our Alma Mater realise that it is absolutely necessary for all of them to stand by Her at the most critical period of the history of Her development?" While reading this letter, we can almost hear the anguished voice of that proud visionary who built Asia's most outstanding university of that time and then saw the creation of his dreams crumble before his own eyes. Physics research in India could never reach the height that it reached during the extremely short golden period of Calcutta University!

Whenever I have discussed this extraordinary history with my non-Indian friends, many of them wanted to know if there exists a coherent account of this history that I could recommend to them. I did not know of any book that covers the history of this extraordinary epoch of physics research in Calcutta comprehensively. There are authoritative biographies of Raman, Bose or Saha, some of which I shall list later in Section 3. However, most of these biographies have been written specifically for Indian readers. For example, a scholarly biography of Bose begins by referring to Bengal, Calcutta and Dacca in the opening paragraph. An Indian reader would be expected to know that Bengal was a province of the British Indian Empire comprising roughly of present-day Bangladesh and the state of West Bengal in India, and that Calcutta and Dacca were the first and second largest cities of that province. A non-Indian reader who does not have this background of geography and history would be quite a bit lost. Also, one can have a full picture of that extraordinary epoch only from a study focussing on that epoch rather than from individual biographies, setting that epoch as a landmark in modern India's search for self-expression against the backdrop of the freedom movement. To the best of my knowledge, no such study focussing on this epoch that would be easily accessible to non-Indian readers exists.

Apart from the dramatic way in which the Physics Department of Calcutta University rose and fell, there are other elements of high drama connected with our history. I give two examples. The first example concerns Raman, who hailed from the Tamil country in the deep south of India and had come to Calcutta in 1907 with a job in the Finance Department. While on his way back from work by tram one day, he noticed the signboard of Indian Association for the Cultivation of Science, which was started by Mahendra Lal Sircar, a successful medical doctor, about a quarter century earlier for the "cultivation of science", but remained a dormant place in which, to Sircar's great disappointment, nobody took any interest. Raman discovered this sleepy place stocked with various kinds of scientific instruments where nobody was working, and Amrita Lal Sircar, the son of Mahendra Lal Sircar who had passed away by then, was believed to have risen to embrace Raman with the words "All these years we have been waiting for a person like you", and made all the facilities available to him. The second example is about the way Bose's famous work got published. When Bose had difficulty publishing his epoch-making paper in *Philosophical Magazine* where he had already published three papers, he sent the paper to Einstein with a covering letter. Einstein immediately understood the revolutionary nature of the paper, himself translated it into German from English and arranged for its publication in *Zeitschrift für Physik.* Later on, Einstein extended Bose's analysis for photons to particles with mass.

Certainly Raman, Bose and Saha belong to the whole world and not just to India. Their story ought be told in a way that is accessible to readers outside India. Even though the history of the physics community in Calcutta at the time of the establishment of the Science College is so rich in human drama, the important question before us is whether we can reconstruct that history reliably and critically with the help of materials available to us at the present time. We look at this question in this paper.

## 2. The Role of our Epoch in the Growth of Modern Science in India

Raman, Bose and Saha occupy a peculiar place in the history of the growth of modern science in India. They were certainly not the first Indian scientists to receive international attention. That honour should go to the physicist J.C. Bose and the chemist P.C. Ray—both teachers at Presidency College in Calcutta—who rose to scientific eminence towards the end of the nineteenth century. Then, just around the time when the Physics Department of Calcutta University was being planned, Srinivasa Ramanujan dazzled the world of mathematics like a brilliant short-lived comet. All these scientists depended on the West in very crucial ways for their creativity. (J.C.) Bose and Ray had their initial training in research in London and Edinburgh respectively. Although Ramanujan wrote his first paper before leaving India, his genius blossomed only when G.H. Hardy got him to Cambridge. Compared to them, Raman, (S.N.) Bose and Saha were completely self-made. None of them ever had a proper research "supervisor". All of them figured out on their own what they wanted to do. The famous discoveries of Saha and Bose were made before they ever stepped-out of India. While Raman had been abroad after his early research made his reputation, that international exposure was probably not too crucial in shaping his subsequent research path leading to the discovery of the Raman effect.

Although the Western influence was so important in moulding the careers of (J.C.) Bose, Ray and Ramanujan, they were often perceived by their contemporaries as the culmination of the Indian tradition. Both (J.C.) Bose and Ray were generally referred to as *Acharyas*—an epithet for great teachers in the Indian cultural tradition. In the case of J.C. Bose, after his early brilliant work on radio waves, when he shifted to studying responses in plants, it became easy to connect him to the Indian tradition which perceived a unity in nature. Although Ray's chemistry research could not be connected to the Indian tradition that way, Ray also carried out pioneering research on the history of Hindu chemistry. In Ramanujan's case, the lack of importance he often attached to mathematical proofs could easily be ascribed to his incomplete training in mathematics in his formative years [6]. However, since mathematical proof was historically given less importance in the Indian mathematical tradition compared to the Greek tradition, one could connect the peculiarities of Ramanujan's genius to his Indian heritage. Ironically, although Raman, (S.N.) Bose and Saha were the first modern Indian scientists whose careers were not shaped by their interactions with the West as in the case of their predecessors and, in that sense, they were more indigenously Indian, they were the first generation of Indian scientists who were generally not viewed as being connected with the Indian tradition. They were simply regarded as international scientists belonging to the global tradition of science.

After these comments on how Raman, Bose and Saha stood in relation to their predecessors, we come to the more important question: how do they stand in relation to their successors? The short brilliant burst of scientific creativity with which they had been associated did not lead to the establishment of a school of physics research. It is vitally important for us to address the question why this extraordinary phase of scientific creativity disappeared as suddenly as it appeared. Was it that conditions in India at that time were such that it was not possible for such a creative phase to continue for too long? Or do we have to "blame" Raman, Bose and Saha in some way that, in spite of their extraordinary achievements, they did not provide the right kind of leadership for the growth of Indian physics? Since Raman, Bose and Saha have been icons of science in India, it has been almost a taboo to raise such a question. Nearly all the Indian authors who wrote on them refrained from analyzing this issue. Now that we can view them from a historical distance, perhaps it is time to analyze this vital issue objectively.

Amal Kumar Raychaudhuri, the most outstanding physicist to come out of Calcutta in the next generation, is remembered for the Raychaudhuri equation which played a crucial role in proving the singularity theorems in general relativity. Raychaudhuri, who had seen Bose and Saha closely, wrote [7]: "The present writer passed out of the University in 1944. I remember how those who were a few years senior discouraged me about taking up research. The feeling was that one should take up any job whatsoever that he may be able to get rather than enter into a field where prospects were simply dismal. To make matters worse an idea went around that scientific research is the business of supermen like Bose and Saha and an ordinary Indian should not be foolish enough to aspire after doing anything worthwhile. Strangely neither Bose nor Saha did anything to counter such absurd ideas—I wonder whether they actually relished it!" Note that Raychaudhuri is referring to the year 1944—only slightly more than a decade after the glorious era of Calcutta physics when many of the heroes of the glorious era were still very much around. How could the mood change so much in such a short time? We have to keep in mind that the national mood as a whole was much gloomier and darker at that time compared to the forward-looking 1920s. That was the time of the Second World War. Bengal was recovering from the terrible man-made famine of 1943. Communal riots between Hindus and Muslims started becoming a frequent occurrence. Still we get a feeling that this societal mood does not fully explain Raychaudhuri's pessimistic outlook. Even at the darkest of times, human spirit has an urge to conquer the circumstances and rise above them. Could it be that Raychaudhuri was a natural pessimist and his view did not really reflect the view of his generation? Raychaudhuri himself and many of his contemporaries had been my teachers in Presidency College in the 1970s. With several of them, I had detailed conversations about their student days. I can assert with confidence that the quotation from Raychaudhuri quite accurately reflects the mood of his generation.

If there is a sudden burst of scientific creativity in a country which did not have a tradition of scientific research, there are opposing examples of that leading to the establishment of a school of research and also that *not* leading to the establishment of a school of research. Let me give two such contrasting examples. In the second half of the nineteenth century when America was in the backwaters of scientific research, Josiah Willard Gibbs, a solitary genius working at Yale University, made very deep and profound contributions to theoretical physics. He was an intellectual recluse who did not leave followers behind him and his influence did not give rise to any school of physics research in the USA. Contrast with this the case of the Russian physicist Lev Landau, a few years younger than Raman, Bose and Saha. Although there had been some earlier Russian physicists who made important contributions to theoretical physics, it was the charismatic personality of Landau, through his teaching and research mentorship, that inspired the whole next generation of Russian physicists and established a very strong school in theoretical physics. If we want to compare the Indian situation with the Russian situation, we have to keep one important factor in mind. It was not easy for a Russian physicist to travel abroad. So the brightest people stayed in the country and produced their best science there. On the other hand, brain drain had a serious impact on the growth of Indian science as countries like the USA became more welcoming to scientific emigres. This, however, does not explain the mood of despondency expressed in the quotation from Raychaudhuri.

When would we expect that a sudden burst of scientific creativity would lead to the establishment of a vibrant scientific tradition? I would like to humbly propose the following answer. Only when there is a community of many active competent scientists, we expect that a few of them may make spectacular discoveries, giving rise to a strong scientific tradition. In a given population, there may be a small handful of unusual geniuses who would rise to scientific eminence even under the most adverse circumstances. Presumably Raman, Bose and Saha, as well as Raychaudhuri in the next generation, belonged to this class. But one cannot have a school of science only with such unusual individuals. There would be a much larger number of persons in the population who have the intrinsic ability to become competent scientists, but who blossom into competent scientists only if they receive appropriate guidance and encouragement in their formative years. A community can have a strong school of scientific research only when this second category of persons are able to realize their full potential. When we consider the generation after the generation of Raman, Bose and Saha, we clearly perceive it as a generation of missing physicists. I can only talk about that generation in Calcutta, because I am not sufficiently familiar with that generation elsewhere in India. Those of us who had the privilege of being taught physics by Shyamal Sengupta, Rashbehari Chakrabarti and Hemendra Nath Mukherji in Presidençy College in the 1960s and 1970s would unanimously agree that they had the potential to become outstanding physicists if circumstances were different in their youth. Their command over physics would easily surpass that of many professors in India's top physics departments today. In spite of the spectacular achievements of Raman, Bose and Saha, why did Calcutta not have an intellectually stimulating atmosphere for physics in the following years? Why many would-be physicists never really blossomed into successful researchers? What caused this generation of missing physicists?

We now come back to the question whether we have to "blame" Raman, Bose and Saha for this. Since we are mainly talking about Calcutta now and Raman left Calcutta in 1933 to take up the Directorship of Indian Institute of Science in Bangalore, let us leave Raman out of our reckoning right now. Although Bose and Saha spent several years in Dacca and Allahabad respectively, both of them eventually came back to Calcutta University—Saha in 1937 and Bose in 1945. There was a period of about seven years (1945–1952) when Saha and Bose were both in the physics faculty of Calcutta University. Many of our outstanding teachers in Presidency

College went through Calcutta University exactly during this period. As I have already pointed out, there have been supremely great physicists like Gibbs who simply did not have the type of personality to inspire the next generation that Landau could do. If Bose and Saha also like Gibbs did not have the right type of personality, then we can feel sorry that physics did not take root in Calcutta in a way we would have liked, but we can hardly blame Bose or Saha for not being Landau! We should blame them only if they did something that was detrimental to the growth of physics in Calcutta. The quotation from Raychaudhuri obliquely hints that Bose and Saha indeed have to be blamed, to some extent at least, for what was happening (or rather what was not happening) in the physics world of Calcutta.

There is now a genre of biography-writing which is essentially slinging mud at great persons. The biographer digs out all kinds of unknown negative secrets in the life of a great man to cut him down to size. I personally have never been an admirer of this genre of biography-writing. But uncritical iconography is not the viable alternative. Raman, Bose and Saha were scientific giants of such colossal stature that even if our analysis shows that they have to be blamed for their negative impact on the growth of Indian physics, that will not diminish the brilliance of their extraordinary achievements. However, an objective analysis of this should have much broader implications for the whole subject of history of science. Such an analysis would enable us to understand better the circumstances under which a tradition of scientific research may develop and flourish, as well as what may stifle such a tradition. The important question is whether we have sufficient source materials available to us at the present time to reconstruct a history of the glorious epoch of Calcutta physics in sufficient detail to make a proper objective analysis possible. We now take stock of the available source materials and address this question.

## 3. In Search of Source Materials

Since less than a century had elapsed after the epoch in which we are interested and many persons who had seen Raman, Bose and Saha in flesh and blood are still alive, one may think that reconstructing a history of that epoch should not be too difficult. But as I started looking for source materials, I quickly realized that this is a much more challenging job than what I initially expected. The scientific papers of all three are easily accessible, since their important papers appeared in standard journals and the collected papers of all of them have also been published [8,9,10]. Saha had written a considerable amount apart from his scientific papers. These writings also have been collected [11]. The collected Bengali writings of Bose and Saha have also been published [12,13].

We do know the broad outlines of the major events in the lives of our three protagonists–Raman, Bose and Saha. Soon after their deaths, short sketches of their lives appeared in *Biographical Memoirs of the Fellows of the Royal Society* written by persons who knew them well and knew about their science (D.S. Kothari wrote on Saha [14], S. Bhagavantam on Raman [15], J. Mehra on Bose [16]). The primary sources of information about the lives of

Bose and Saha are the short biographies penned by Santimay Chatterjee, a Calcutta-based physicist, and his writer-wife Enakshi Chatterjee [17,18]. Santimay Chatterjee had done research under Saha's supervision and had known both Bose and Saha personally. Although the biographies were written after the deaths of Saha and Bose, Chatterjees got quite a lot of their information from the family members of Saha and Bose. Afterwards Santimay Chatterjee, in collaboration with others, prepared a fuller biography of Bose on the occasion of his birth centenary [19]. The most detailed account of Raman's personal life can be found in the biography by Uma Parameswaran [20], who was the granddaughter of Raman's elder brother. She got much of her information from family members—especially from Raman's wife Lokasundari, who lived for several years after Raman's death and whom Parameswaran knew intimately. S. Ramaseshan, Raman's nephew who carried on research under Raman's supervision, also wrote several articles on Raman as scientist and man [21]. A monumental scientific biography of Raman was written by G. Venkataraman [22], who also wrote excellent short scientific biographies of Bose [23] and Saha [24]–describing the scientific achievements of all of them against the backdrop of physics of their time. Venkataraman has been much more critical than a typical biographer of an Indian cultural icon. An account of Raman's scientific work at Calcutta was prepared by S.N. Sen [25], the doyen of history of science research in India, who also edited a volume on Saha's life and works on the occasion of his 60th birthday [26]. Since Saha himself went through this material, the account given in this volume can be taken to be the authorized account of Saha's life and works as he would have liked to be passed on to posterity. Finally, Rajinder Singh has written a study on the discovery of the Raman effect and its international impact, leading to the Nobel Prize [27].

As I have pointed out, our interest is to reconstruct the history of an extraordinary epoch rather than of individuals. One may naively think that we merely take the materials from the above-listed biographies pertaining to the epoch of our interest and combine these together to reconstruct the history of this epoch. A quick perusal of the biographies listed above shows that this will not do—one simple reason being that most of these biographies have only very limited amount of material concerning the questions of what made this extraordinary epoch possible and why it faded away so quickly. For example, in Venkataraman's biography of Raman running to more than 500 pages [22], only about 20 pages are devoted to events during Raman's golden years when he was working in Calcutta (1907–33). In the cases of many famous persons (including Jesus Christ), it is much easier to get information about them after they became important public figures. It is much harder to gather information about early stages of their lives before they became famous. I should mention that there are some valuable studies which cover the later lives of our protagonists. Robert Anderson has published a detailed and thorough study of Saha as an institute-builder by comparing him with the other institute-builders of India of that time (Bhabha, Bhatnagar) [28]. Just like this study, an interesting study of Raman and Saha from a feminist viewpoint by Abha Sur [29] also focuses on the later phases of their lives when they were public figures.

Biographies of famous persons are secondary source materials. Do we have enough of more primary source materials on which we can rely in order to reconstruct our history? To understand intellectual creativity, often an account of the external events is not sufficient. We need to know how the creative person responded to various influences and what might have been going through his mind to enable him to be so creative. Unless we have a record of what a great man thought at a certain time, we have to guess what might have gone through his mind based on the available data. The personal papers of the great man—private and official letters, memoirs, recorded speeches—often constitute the primary source materials that allow us a glimpse into the great man's mind and give us a key to understanding the creative process. Reminiscences by contemporaries constitute another valuable primary source material. Do we have such source materials for Raman, Bose and Saha available to us? Thanks to Saha's children, his personal papers have been preserved. Saha himself was an organized man and kept all his personal papers systematically arranged. At one stage a few years after his untimely death, his children had to decide what should be done with these personal papers. They decided to deposit the personal papers in the archive of Nehru Memorial Museum and Library, New Delhi, after making two copies of the entire set of papers—one set of which is kept at the Saha Institute of Nuclear Physics in Calcutta and the other set at the home of Saha's daughter Chitra Roy. Each set consists of a few thousand pages. To the best of my knowledge, there has been only one detailed study of Saha's personal papers (in Bengali) by Atri Mukhopadhyay [30]. Not much of the material in the Saha archive has ever been published. Unfortunately Bose was the extreme opposite of Saha and never kept his personal papers systematically. Very little of his personal papers seem to have survived. However, in his old age, Bose was quite fond of reminiscing about his youth. He never wrote a long coherent autobiographical account. But his reminiscences are scattered through many pieces—mostly in Bengali. A few of these pieces were translated into English on the occasion of Bose's birth centenary. But one has to browse through Bose's collected writings in Bengali [12] for the other autobiographical clippings. Perhaps the fate of Raman's personal papers is the most intriguing. There is enough evidence that Raman also kept his personal papers organized very systematically—just like Saha. What happened to his personal papers? Nobody seems to know an answer to this question! I have personally enquired at the five organizations with which Raman had been associated—Indian Association for the Cultivation of Science, Calcutta University, Indian Institute of Science, Raman Research Institute, Indian Academy of Sciences. Apart from some stray documents, none of these organizations has a substantial systematic collection of Raman papers. Unfortunately, in India, for a long time there was no awareness that such materials are of inestimable historical value and should be preserved properly. I wonder if this is due to our Vedantic view that life is a transitory illusion! Every historian knows that records of ancient India are much sparser compared to the records of other ancient civilizations. Only within the last few years, several Indian organizations have at last started building archives to preserve their historical records. In fact, people in all the organizations with which Raman had been associates are now looking for Raman materials. We can only hope that the Raman papers are still gathering dust in some unknown shelf of a storeroom in one of these organizations and will be discovered in the near future. Right now, we have to proceed with the assumption that the personal papers of Raman are largely lost.

There is one other extremely valuable source for reconstructing the history of our extraordinary epoch that has so far been explored very superficially—the records of the Syndicate and the Senate of Calcutta University. In the early years of the twentieth century, Calcutta University used to keep these records in unbelievable detail. Very often, minutes of important meetings would include very detailed statements of the persons who spoke at these meetings. For example, the records of the year 1924 alone run to a whopping 3550 pages!!! It is certainly not easy to dig out the material you are interested in from these records. Recently Calcutta University has taken the initiative to put these records on the Internet. In his study of Raman's scientific work at Calcutta, S.N. Sen [25] quotes a few extracts from these reports describing discussions in which Raman took part. These extracts quickly dispel the general perception that Raman was so involved with his work at the Indian Association for the Cultivation of Science that he did not take much interest in the affairs of Calcutta University. For example, Raman strongly argued in support of those who wanted to introduce Bengali at the highest levels of Calcutta University, although Raman himself could not speak or understand Bengali. I know of only one scholar who has made extensive studies of the records of Calcutta University–Dinesh Chandra Sinha, who retired as the Deputy Registrar of the University. A number of articles he wrote on various aspects of Calcutta University (written in Bengali, though various documents are quoted in the original English) have been collected together in a book [31]. This book has two articles on Saha and Raman, quoting several fascinating official letters between them and the University. I have already quoted the letter from Mookerjee to Saha on the financial crisis of Calcutta University [5]. This letter is given in full in Sinha's book. Sinha must have obtained these letters from files kept in some office of Calcutta University. Most of Sinha's articles were written more than two decades ago. Clearly these files existed at that time. Even after making several enquiries at Calcutta University, I have not been able to find any information where these files are kept now or if they still exist. When I tried to find contact details of Sinha in order to meet him personally, I discovered to my regret that he had passed away just a few months earlier. Although Sinha wrote two articles on Saha and Raman reproducing several official letters to and from them, Sinha unfortunately did not write a similar article on Bose. When Santimay Chatterjee was preparing the biography of Bose on the occasion of his birth centenary in 1994, he visited Dacca University in search of source materials. He found several official letters between Bose and Dacca University neatly filed. Some of these letters are quoted in the biography of Bose prepared for his birth centenary [19]. We do not find similar official letters between Bose and Calcutta University quoted in that biography. My guess is that Chatterjee must have looked for such letters and could not find them. So, already in 1994, Bose's file at Calcutta University was not accessible to scholars. Again, with the increased awareness about the value of such materials, we can only hope that the files of Raman, Saha and Bose, as well as the files of other famous professors of Calcutta University of that period, will be discovered some day from some godown and will thereafter be preserved carefully for posterity.

Raman joined the Physics Department of Calcutta University in 1917 and Saha left for a tour of Europe in September 1919. By the time he returned, Bose had already left for Dacca University. So probably only two or three batches of M.Sc. students during the years 1917-1919 had the privilege of being taught by Raman, Bose and Saha simultaneously. All three of them were young men who still had not made their famous discoveries and students probably could not guess that one day these three would be legends of physics. What was it like to be an M.Sc. student in the small Physics Department of Calcutta University at that time? Who taught what? Was the teaching exciting? What were the examinations like? Can we reconstruct the intellectual atmosphere of the Department at that time? From the documents I have so far looked at, I could not even find out how many students were there in each batch. We would like to know the names of the students in these first batches, whether some of them turned out to be professional physicists and what the others did after M.Sc. As the Physics Department of Calcutta University is approaching its centenary, I find that a few colleagues are interested in finding answers to these questions*. There is a plan of searching the records of Calcutta University in the next few months and hopefully we shall have at least partial answers to some of these questions. If we could have a reminiscence of the Physics Department of Calcutta University in those early years, that would be wonderful. While I am not aware of anybody who wrote such a reminiscence, it will probably not be easy to trace such a reminiscence even if somebody had written it. I have already mentioned that Sailen Ghose, who built the M.Sc. physics laboratory and then could not join the faculty because of his connection with the revolutionaries, wrote a reminiscence for the magazine *Asia* [2]. All my efforts of finding this reminiscence anywhere in Calcutta failed, although it was reprinted in Calcutta in 1992 in the *Sailendranath Ghosh Birth Centenary Commemoration Volume*. Usually such volumes are not kept and catalogued in libraries. Ultimately I came to know that Vivek Bald of Massachusetts Institute of Technology, who was studying immigrants to America from the Indian subcontinent, was interested in Sailen Ghose as an eminent immigrant. On contacting Bald through e-mail, he told me that he managed to get those old rare copies of *Asia* through great difficulty and kindly sent me a scanned soft copy of the Ghose reminiscence. While discussing reminiscences, I shall mention another unusual document. Raman's student K. S. Krishnan, who was involved in the discovery of the Raman effect and about whom many feel that more credit should have gone to him, kept a diary describing the work done in the laboratory. The mysterious thing about the diary is that several pages starting from the day on which the Raman effect was discovered have been torn out. Nobody knows what happened to these missing pages. A detailed biography of Krishnan has been written by D.C.V. Mallik and S. Chatterjee [32].

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* See the article on the first twenty years of the Department in this volume, where some of the questions have been answered.

It appears that chemists have been more interested in writing reminiscences than physicists. The great P.C. Ray—who taught at Presidency College in Calcutta (where Bose and Saha were his students) and then joined Calcutta University as the Palit Professor of Chemistry at the invitation of Asutosh Mookerjee—wrote a fascinating autobiography both in English and in Bengali [33]. This invaluable autobiography gives a detailed account of the establishment of the Science College of Calcutta University and the subsequent difficulties it faced from an insider's point of view. Another interesting reminiscence in Bengali is by P.C. Rakshit [34], who was a student of Jnanendra Ghosh (whom Mookerjee mentioned in his letter to Saha quoted earlier [5]) in Dacca and has given an intimate portrait of Bose during his Dacca years.

In order to put the brilliant epoch of Calcutta physics in proper historical context, we need to know how modern science grew in India. A brief account of how Western science started in India has been given in the seminal work on the history of Indian science by Bose, Sen and Subbarayapppa [35]. Fuller accounts are given by Pratik Chakrabarti [36] and Chittabrata Palit [37]. J. Lourdusamy studied the four pioneers [38]–Mahendra Lal Sircar, Asutosh Mookerjee, J.C. Bose, P.C. Ray. Detailed studies of Mookerjee and Ray in Bengali have been carried out by Shyamal Chakrabarti [39,40]. The authorized biography of J.C. Bose was by his maverick friend Patrick Geddes [41]. See also a recent volume with three long critical essays on Bose [42]. Ashis Nandy carried out an interesting study of Bose and Ramanujan from a psychoanalytical point of view [43].

Lastly, I should mention the institutional histories. Calcutta University was established more than half a century before Mookerjee started the Science College. On the occasion of the centenary of Calcutta University in 1957, a group of scholars produced a history of the University [44]. Before the establishment of the Science College at Calcutta University, there were two serious efforts of starting organizations for scientific research: Indian Association for the Cultivation of Science in Calcutta (which was discovered by Raman from a tram on his way home) and Indian Institute of Science in Bangalore (of which Raman became the first Indian Director in 1933). A history of the first organization was compiled at the time of its centenary [45], whereas a history of the second organization has been written by B.V. Subbarayappa [46]. Just as the first organization was a dormant sleepy place in its first few decades, the second organization also had an undistinguished start. In fact, the failure of Indian Institute of Science to produce any worthwhile science in its first years was a matter of concern when Mookerjee was planning the Science College in Calcutta. The primary reason for the failure of Indian Institute of Science was that the British rulers of India were using it as a parking place for second- and third-rate British academics who could not find any positions in Britain. To avoid this from happening in Calcutta University, Mookerjee always insisted that the donors whose donations created the various named chairs put the condition that these chairs can only be offered to Indians. This was another reason behind the wrath of the British rulers against Calcutta University.

In this survey of source materials, while listing secondary source materials, I have restricted myself mainly to the most important book-length studies. There have also been numerous articles and essays in many journals and magazines that throw important light on our topic. Since Raman, Bose and Saha are icons in Indian science, there have also been many short descriptive books on them—written specially for children and young people. I have primarily cited those books which appeared to me to be historically sound and critical in a scholarly way.

## 4. Can We Reconstruct the History?

After this survey of source materials, let us come to the question whether we can adequately reconstruct the history of the glorious period of physics research at Calcutta University. Certain documents which would have been of inestimable value in reconstructing this history are not available to us—the most important being the personal papers of Raman and Bose, as well as the official files of Raman, Bose and Saha with Calcutta University. There is a small chance that some of these documents may be discovered in the coming years. However, since we are not certain of this, we should make an attempt at reconstructing the history as best as we can, on the basis of what we have available to us today. Since we can now view Raman, Bose and Saha from the distance of a few decades and most of the persons who had been involved in close scientific interactions with them are no longer alive, we can now analyze many events connected with them objectively without hurting the feelings of any living persons. One thing is clear. If we treat Raman, Bose and Saha as faultless supermen that many of their biographers would like us to believe, then we shall never be able to address certain important questions—such as why the brilliant epoch of physics research did not lead to the establishment of a strong tradition of physics research in India. To analyze this issue adequately, we have to treat them as intellectual giants who nevertheless had many human failings.

A few persons who had known Raman, Bose or Saha intimately are still alive. One important question is whether we can obtain valuable data for reconstructing our history by interviewing them. I believe that what we can learn from such interviews is not only of limited value for our study, but can actually be quite misleading. These still living persons have all seen these great men in the twilight years of their lives. We know that all living beings change with age. In the cases of all three of our protagonists, there seem to have been some critical phase transitions in their personalities—approximately in the early 1930s in all the cases. So the three elderly men whom the still living persons knew were entirely different persons from the three young men who revolutionized physics. If we try to interpret the events of 1920s on the basis of the impression we gather from people who have seen these great men in the 1950s and 1960s, then we shall be mistaking apples for oranges. One simple example will suffice. Although I have never come across detailed and objective accounts of the teaching of Bose and Saha in their younger years, there is evidence to suggest that they were dedicated and inspiring teachers in their younger years. Perhaps the biggest support in favour of this is Saha's extraordinary textbook on thermal physics [47], presumably the best physics textbook ever written from India. Having myself written two critically acclaimed textbooks, I personally know what is involved in writing a textbook and I cannot believe that a person who was not completely dedicated in teaching could have written the textbook that Saha wrote. However, a few persons who have been taught by Bose and Saha when they again returned to Calcutta University are still alive. Over the years, I had detailed discussions with at least half a dozen of them (including some who are not alive today). I got the uniform opinion that attending lectures by Bose or Saha was an extremely disappointing experience. They both taught in a way as if they had lost all interest in physics and teaching was an onerous burden in which their heart was not there. Bose and Saha, who taught at Calcutta University in the years immediately preceding their retirement, were totally different persons from the young men who took up the teaching of newest developments in physics as a challenge thrown to them by Asutosh Mookerjee!

In Indian society, writing anything negative about somebody who had become a cultural icon is often considered a taboo. Without exception, all the persons who told me about Bose's and Saha's unsatisfactory teaching made it clear to me that they would not like their statements to be recorded or would not want to be quoted with their names. In scholarly writing, the standard practice is to provide any information only with full details about the source of that information. Although it is still possible to gather anonymous data about Bose's or Saha's teaching in their later years from persons who are still alive, it is not easy to prepare a scholarly account of their teaching with proper accrediting. The same difficulty arises when we try to obtain any negative information about the personal lives of these great men. Often negative developments in personal life affect a person's intellectual creativity at a deep level and a knowledge of such developments is often important to explain the patterns of creativity. I give an example to demonstrate how difficult it is to obtain such negative information about a famous person. Raman's elder son Raja fell out with his father, because both of them had dominating but incompatible personalities. During his adulthood, Raja never had any contacts his father, though I have heard that his mother secretly used to help him with money. Except Uma Parameswaran [48], none of the other biographers of Raman even acknowledged Raja's existence! One gentleman who was close to the Raman family told me the following about Raja: "He was a very intelligent man and the sharpness of his mind would be apparent even in casual conversation. He never married. He became a communist in his youth. Since Raman hated communists, that was the beginning of the breakup of his relation with Raman. Afterwards Raja converted to Islam. Although he lived in the Muslim neighbourhood in a Bangalore locality called Kodigehalli, he and Raman never saw each other during Raman's final years. I often used to visit Raja in his last few years. He told me that I could visit him only on one condition: I should never disclose his family connections to his neighbours. Once when I went to his house, I found it locked. On enquiring with the neighbours, I came to know that he had passed away about a week ago. None of the neighbours knew anything about his family and could not contact any family members. He was buried in an unmarked grave in the nearby Muslim graveyard." When I asked this gentleman if I could quote him with his name in scholarly writing, he told me that he would disown ever making such statements to me if I quoted him with his name!

When Bose and Saha returned to Calcutta after their innings in Dacca and Allahabad respectively, they were legends in Indian science. Calcutta has been known for a long time as a city where some of the brightest students were interested in physics. One would have expected some of these brightest students to flock around Bose and Saha to learn physics from them and to work under their guidance. Something like this does not seem to have happened. Purnima Sinha, who did her Ph.D. thesis under Bose's supervision and worshipped Bose as a demigod, gave a very bizarre explanation of why the brightest students did not work with Bose [49]: "He never tried to establish a school by gathering the best students around him. After all, the best students can always find their own paths. But who will look after the less capable students? The great savant therefore took upon himself the job of guiding such students." I am aware of only one frank depiction of the atmosphere of the Calcutta physics community in the 1940s and 1950s–written by none other than Amal Raychaudhuri of the Raychaudhuri equation fame. It is an extremely frank 30-page autobiographical note (in Bengali) written when he was convalescing from a serious illness. Although he lived for three years after this note was written, it was never published during his lifetime. After his death, his daughter decided to publish it [50]. Over the years, I had heard many of these things written in the autobiographical note directly from Professor Raychaudhuri. He used to tell us that he wanted promising physics students of the next generation to know of this history, but he could never think of having this history published. We are fortunate that we now have this valuable document. It gives a grim and unflattering portrait of the Calcutta physics world when Bose and Saha were the living icons. We are quite shocked to know of the way Bose and Saha would interact with young budding physicists of that time. While Bose never tried to build a research group around himself, Saha had a thriving research group at Allahabad and several members of this group became respected physicists afterwards. We feel extremely saddened to read the account of Raychaudhuri—especially when we contrast with it several accounts that we have of Saha's extraordinary kindness to his students in Allahabad. How could an idealistic man who was so inspiring and charismatic in his younger days change so much?

When several persons of exceptional intellectual ability are put in the same place, two opposing things can happen. On the one hand, interactions amongst them can create a vibrant intellectual atmosphere and enhance the creativity of everybody around. On the other hand, if resources—laboratory space, funding, positions—are too limited for several extraordinary individuals to grow together, that can also lead to a Darwinian struggle for existence. Both of these things happened within the Calcutta physics community. Although Bose and Saha were rivals in the B.Sc. and M.Sc. classes, they were extremely intimate friends in their youth and interacted closely. Apart from writing a joint paper (Bose's first paper), they together prepared the first English translation of Einstein's papers on relativity, barely three years after the publication of Einstein's famous work on general relativity [51]. Apparently Bose's famous work on Bose statistics done in Dacca was also triggered by Saha, who had come to Dacca for some official work and discussed some recent papers, making Bose interested in the problem of energy distribution of photons [52]. Although Bose and Saha never fell out with each other, the intensity of friendship diminished considerably in their later lives. When I asked Saha's daughter Chitra Roy whether Bose sometimes visited Saha at his home or Saha visited Bose at his home when they were both in Calcutta in their later years, Chitra Roy could not recollect any such visits.

To collect reliable information about the conflicts amongst scientists is much more difficult than to collect information about their cooperation. Both Raman and Saha had strong dominating personalities. It is clear that each man admired the other for the other's physics contributions. However, there was a clash of egos between these two titans in the early 1930s that had a disastrous consequence for Indian science. I have mentioned about the drastic changes in the personalities of Raman and Saha. These changes more or less coincide with this clash, making us wonder whether this unfortunate clash was a major contributor in the changes of their personalities. It is not easy to find reliable information of exactly what happened. Some biographers have squarely taken the side of their biographees. For example, Uma Parameswaran [20], the biographer of Raman, would like us to believe that Raman was a faultless person of childlike simplicity who was not to be blamed for any conflicts he was involved in. On the other hand, Atri Mukhopadhyay [30], who studied Saha's private papers, projects Saha as an innocent victim of the conspiracies hatched by others against him. I find G. Venkataraman to be the *only* author who has been impartial and made the following perceptive comment [53]: "Clashes between strong personalities are not uncommon and they are to be found everywhere and at all times. But in the academic world, one seldom witnesses events such as those which occurred in Calcutta. The basic problem there was that there was not enough room for both the giants. If only the country had been rich enough to afford several faculty and student positions, this conflict might never have gone beyond minor skirmishes."

But even Venkataraman reconstructed events "based on conversations with persons who had first-hand knowledge" and not on the basis of proper documentation. According to Venkataraman, Saha was interested in a professorship created at the Indian Association for the Cultivation of Science and requested the support of Raman, who was the Secretary of the Association. Raman, who wanted this position to be offered to his former student Krishnan, wrote back saying that "lately Saha had not been much concerned about research; what the Association needed was an active young man on his way up rather than one who had reached a plateau" [54]. These letters between Saha and Raman have not been found! Atri Mukhopadhyay dismissed this version as a story fabricated by Raman's supporters. Perhaps the account of the events in a fateful meeting at the Indian Association for the Cultivation of Science that Mallik and Chatterjee [55] have given is as much as we can now establish on the basis of documentary evidence. But what Saha wrote in a letter to P.C. Ray indicates that there were more things happening and the version of Venkataraman may have some truth. Saha's language in the letter is quite shocking [56]: "Prof. Raman will have to know that if he does not leave the Science Association to Bengal, he will have to meet with determined opposition from me. Ten years' administrative experience at Allahabad have not been in vain. He will find a Tartar in me, and you may drop him a hint that is not my only trick. I have got many other obstructive tactics up my sleeve. This time I placed my cards on the table, but next time, I shall not give him even this chance. I will confront him with the difficulties on the spot and make him dance."

While these conflicts rose to a crescendo in the early 1930s, there were tussles for scarce resources as soon as the Science College of Calcutta University was established. J.C. Bose and Raman were the two outstanding experimental physicists of that era. It is unfortunate that they fell out with each other very soon. S.N. Bose, who had seen this encounter from a close distance, reminisced many years later [57]: "When we were students, the professors used to hold on to their mechanics as some of the most precious possessions... there was a mechanic with Sir J.C. Bose and he did very fine work—indeed to his amazement. Because Sir C.V. Raman had cast his jealous eyes on this mechanic... he grew furious... this Sir J.C. Bose wouldn't forget and wouldn't forgive." In fact, J.C. Bose was so furious that he wrote an angry letter to the Vice-Chancellor of Calcutta University, complaining that Raman was trying to lure away this mechanic by offering a much higher salary [58]. While this might have been acceptable in the American academic world, this was certainly unacceptable behaviour in India of that period. Given the fact that J.C. Bose was not employed at Calcutta University, his writing a letter to the Vice-Chancellor clearly shows how disgusted he was. Several years later, when Raman was felicitated by the Mayor of Calcutta on receiving the Nobel Prize, all the important persons in the Calcutta scientific world were there, except J.C. Bose. While there could be other simple explanations for this absence (illness, not being in Calcutta on that day), it appears that the relationship between J.C. Bose and Raman always remained strained. However, when Sommerfeld visited India, J.C. Bose accompanied him for a visit to Raman's lab [59]. Clearly J.C. Bose did not want a distinguished scientist from abroad to know of their differences.

Abha Sur has written about a seminar at Harvard in 1998 [60]: "[The] speaker showed a group photograph of scientists and went about identifying all the European and American scientists in the picture. In cases where the speaker did not know the identity of the scientist, the audience was asked for help. There was C.V. Raman right in the middle of the front row of the picture in his big turban, conspicuous in his difference from the rest of the scientists, but the speaker's pointer simply slid over his imposing personality without a pause, without any hesitation whatsoever. The otherwise alert and inquisitive audience seemed not to mind the omission."Although every physicist around the world is expected to know of the famous works of physics connected with the names of Raman, Bose and Saha, the extraordinary story of how they created their physics fighting against all odds remains largely unknown and untold to the international physics community. This story needs to be told, even if we do not have all the source materials to reconstruct the full history. While this is an uplifting and dramatic story of how the human spirit can conquer many obstacles, this is also a story of great sadness: a story of how the human failings of the extraordinary individuals who created this glorious epoch of physics—all fiercely patriotic and idealistic in their youth—coupled with forces in the colonial setup that was beyond their control, finally extinguished the light that shone with such brilliance for a short epoch.

## References

[1] This meeting has been described by S.N. Bose in an autobiographical article written in Bengali: *Satyendra Nath Basu Rachana Sankalan* (Bangiya Vijnan Parishad, Calcutta, 1980), pp. 226–227. Asutosh Mookerjee's tenure as Vice-Chancellor ended in 1914, though he was again appointed Vice-Chancellor a few years later. Most probably this meeting took place in 1915 when Ghose, Bose and Saha completed their M.Sc. Mookerjee was not the Vice-Chancellor exactly at that time, although he was still very much giving shape to the new activities initiated at Calcutta University.

[2] Sailendra Nath Ghose, "An Indian Revolutionary", *Asia*, Part I: p. 586 (July 1927); Part II: p. 671 (August 1927); Part III: p. 737 (September 1927).

[3] S. Ramaseshan and C. Ramachandra Rao, *C.V. Raman: A Pictorial Biography* (Indian Academy of Sciences, Bangalore, 1988), quote at pp. 15–16.

[4] *Sir Asutosh Mookerjee: A Tribute* (University of Calcutta, 2013), quote at p. 198.

[5] Dinesh Chandra Sinha, *Prasanga: Kolkata Biswabidyalay* (University of Calcutta, 2007), quote at p. 250.

[6] A fascinating account of Ramanujan's life has been given by Robert Kanigel, *The Man Who Knew Infinity: A Life of the Genius Ramanujan* (Washington Square Press, 1991). This book portrays the academic environment in another region of India at the beginning of the twentieth century.

[7] Amal Kumar Raychaudhuri, *A century of progress* (unpublished manuscript). Courtesy: Subinay Dasgupta.

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# First 20 Years of the Department: From the Archive of the University Syndicate

**Gautam Gangopadhyay and Anirban Kundu**
Department of Physics, University of Calcutta

The departments of basic sciences of the University of Calcutta would not have started, flourished, or come to its present status without the active involvement and vision of its Vice-Chancellor par excellence, Sir Asutosh Mookerjee. Bolstered by the princely endowments by two of the eminent lawyers of the Calcutta Bar, namely, Sir Taraknath Palit in 1912 and Sir Rashbehary Ghose in 1913, he laid the foundation stone of the University College of Science at 92, Upper Circular Road, on March 27, 1914. His tenure as Vice-Chancellor ended just three days after the laying of the foundation stone; he again came back as the Vice-Chancellor after seven years.

The post-graduate teaching started in 1916. This was not the first place to teach M.Sc. in Physics in Calcutta; that honour goes to the Presidency College (PC). In the list of post-graduate teachers, we see names from both University and PC. Every paper, from 1918 onwards, were set by two teachers, one from the University, the other from PC. This practice went on for a very long time.

Palit's grant, in two separate instalments, amounted to about Rs. 14 lac, in cash and property, for creating Professorial chairs in Chemistry and Physics, for providing research fellowships, and setting up of laboratories. Research scholars, research assistants, and assistant professors could be supported from this grant [1].

Ghose's grant was Rs. 10 lac, for four Professorial chairs as well as research fellowships. Chairs were created in the Department of Physics in the names of both. Later, Ghose made another endowment, out of which Ghose chairs for Applied Physics and Applied Chemistry were created.

We pick up the thread from January 1914, about two months prior to the end of Asutosh Mookerjee's first term as the Vice-Chancellor. The Department had a number of stalwarts in the initial years, and it is always tempting to focus on them. In fact, writing anything about the Department without those names is impossible, because they shaped the Department, but as we move through the archives of the Syndicate, we see that there were many not-so-illuminated names too, responsible for the growth.

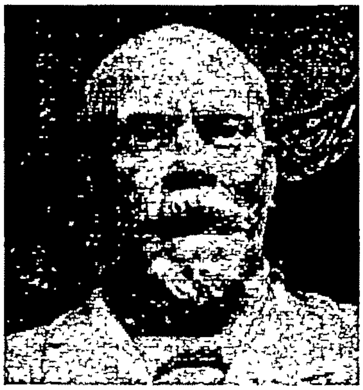
From the minutes of the Syndicate, archived digitally by the University, we pick up some information involving the Department during the first twenty years of its journey, and end in 1936, when Syamaprasad Mookerjee was at the helm of the University. This is by no means complete, or even representative, as none of us is a proper historian. However, the glimpses are interesting, and may serve as a telescope to the distant past. We hope that some historian may take up the task to compile a proper narrative from these minutes.

We will refrain, as much as possible, from repeating what is already widely known and well-documented, like the discovery of the Raman Effect, the Saha equation, or the interaction between Raman and Saha. Also, the spelling of names, both first and last, vary from one document to other: Sircar and Sarkar, Rashbehary, Rasbehari, and Rasbihari, Ghose and Ghosh, Chakrabarti and Chuckerbutti, Bose and Basu, Meghnad and Meghnath. We will follow the commonly used spelling everywhere.

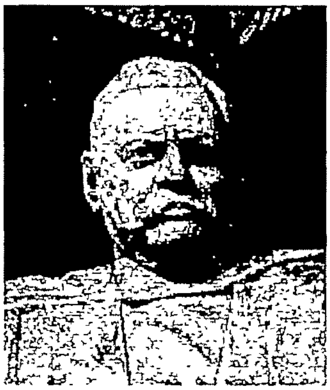
## The Beginning and the Endowments

On December 26, 1913, the Syndicate resolved to advertise for two Palit Professors, in Physics and Chemistry, and four Ghose Professors, in Applied Mathematics, Physics, Chemistry, and Botany [2]. The salary of the Palit Professor was Rs. 10000 per annum, and that of the Ghose Professor Rs. 6000 per annum. The actual appointees got slightly different salaries.

Sir Asutosh Mookerjee



Sir Taraknath Palit



Sir Rashbehary Ghose

The last date of receiving the applications was January 14, 1914. The meeting of the Governing Body (GB) of Sir Taraknath Palit Endowment was held on January 24, 1914. The members present in the GB meeting were Sir Asutosh Mookerjee, Vice-Chancellor, in the Chair ex-officio, Ramendrasundar Tribedi, Dr. P.J. Bruhl [3], J. Watt, S.P. Sinha, Justice B.K. Mullick, and Dr. Nilratan Sircar.

A summary of the applications had been previously circulated to the members. The GB specified that the duties of the professors were to devote themselves to original research to extend the bounds of knowledge, to stimulate and guide advance students in the University College of Science and generally to assist in post-graduate studies and research of advanced students. The professor would also superintend the formation and maintenance of the laboratory in the University College of Science.

The emolument of the Palit Professor would be Rs. 800 per month rising to Rs. 1000 by an annual increment of Rs. 50. In contrast, the starting salary of a University Lecturer was Rs 200 per month. The two Professorships were permanent positions, though ultimately the Ghose Professorships in Physics and Botany were offered for a tenure of seven years. Apart from other regulations, additional leave for ill-health or private affairs were to be guided by the Civil Service Regulations for Officers of the Indian Educational Service.

Dr. P.C. Ray was offered the Palit Professorship of Chemistry.

Mr. C.V. Raman, M.A. was offered the Sir Taraknath Palit Professorship of Physics. The GB noted that "Mr. C.V. Raman had a brilliant career in the University of Madras and is now an officer in the Indian Finance Department. His first paper on "*Unsymmetrical Diffraction Bands due to a Rectangular Aperture*" was published in the Philosophical magazine in 1906, while he was still an M.A. student. Since then, he has been steadily engaged in research work, which has latterly been carried out in the Laboratory of the Indian Association for the Cultivation of Science. His investigations on the theory of Vibrations and on Optics, which have attracted considerable notice among European Physicists, are embodied in twenty-two papers, of which seven have been published in the Philosophical Magazine, three in the Physical Review, six in Nature and the remainder in the Journal of the Indian Mathematical Society and the Bulletin of the Indian Association for the Cultivation of Science. In 1913, the University of Madras awarded to Mr. Raman the Maharaja of Trivandrum Curzon Prize for Research."

The Board of Management of Dr. Rashbehary Ghose Endowment met on the same day. The members present were Sir Asutosh Mookerjee, in the Chair ex-officio as Vice-Chancellor, Ramendrasundar Tribedi, S.C. Mahalanabish, Dr. P.J. Bruhl, Jnanranjan Banerjee, Dr. Prafulla chandra Roy, and Mahendranath Ray.

The Endowment supported four professorships, one each in the subjects of Applied Mathematics, Chemistry, Physics and Botany. The summary of the applications had been circulated among the members earlier. There were eight studentships along with the four Ghose chairs with a salary of Rs. 900 per annum each. A necessary condition for the Ghose

Professorship was that the chairs would always be filled by Indians, *i.e.*, persons born of Indian parents as contradistinguished from persons who are called Statutory natives of India. Asutosh Mookerjee, P.C. Ray, and Mahendranath Ray were nominees of the founder.

The duties of the Professors, specified by the Board, were identical with those decided by the GB of the Sir Taraknath Palit Endowment Trust. The monthly salaries of the Professors were fixed at Rs. 600 for the Professorship of Applied Mathematics and Rs. 500 for the other three professorships. The appointments were permanent in the cases of Applied Mathematics and Chemistry. Professors of Physics and Botany were for the term of seven years, including the two years to be spent at some university outside British India, like continental Europe, America, or Japan. The Senate decided the place where the Ghose Professors would be going for higher studies.

The reasons for the discrepancy in the salaries and the terms of appointment were not recorded in the Minutes. One may speculate that since the Professorship of Applied Mathematics would be offered to Dr. Ganesh Prasad, who was aged 38 and already at a permanent position in the Queen's College, Benares, it was imperative that his salary be higher and the position be permanent. Similarly, the Profesorship of Chemistry was offered to Dr. Prafulla Chandra Mitra, already a University Lecturer in Chemistry. The consideration of the appointment of the Professor of Botany was postponed. It was later offered to Dr. S.P. Agharkar.

Mr. Debendramohan Bose, Professor in the City College, Calcutta, was appointed to the Ghose Professorship of Physics for a term of seven years subject on condition that he spends the frst two years in such University or Universities outside British India; Berlin was chosen by the Senate. The Board of Management had the following to say of D.M. Bose: "Mr. Bose is a distinguished graduate of this University; he was first in the First Class in Physical Science at the M.A. Examination in 1906 and was subsequently awarded a Research Scholarship by the Government of Bengal; subsequently he joined the University of Cambridge and worked in the Cavendish laboratory under Sir Joseph Thomson for over three years. In 1911 he took a First Class at the B.Sc. Honours Examination in the University of London."

The Syndicate approved the proceedings of the two Bodies on January 24, 1914 itself. The Senate approved the appointments in its Annual Meeting on January 30, though there was an interesting debate on it, some European members accusing Sir Asutosh of forcefully pushing through the important agenda like the selection of the Professorial Chairs.

So, who was the first Professor of the Physics Department? Both Raman and Bose were appointed on the same day. Bose was on the university payroll from 1914; Raman joined officially on 1917. But Bose could come back to Kolkata and to the Department only in 1919, when Raman was already established there. Being the Palit Professor, Raman was also ex-officio the Head of the Department. However, two Lecturers joined in 1916: Jogeschandra Mukherjee and Phanindranath Ghosh, at a scale of 200-25-500.

Apart from the Professors, the University could directly appoint Lecturers. Tenured

Assistant Professor positions were also available under the Palit grant. Some of them were absorbed as University lecturers later.

The Khaira Fund, from Guruprasad Singh of Khaira, came in 1921. Five chairs were created: Indian Fine Arts (called Bageswari Professorship), Phonetics, Physics, Chemistry, and Agriculture. The last four would be called the Guruprasad Singh Professorship. The original board for the Khaira Fund included four persons by name, who were allowed to name their successors: Rabindranath Tagore, Jagadischandra Bose, Nilratan Sircar, and Asutosh Mookerjee.

On the recommendation of the syndicate, the senate appointed, in 1921, the following gentlemen as Professors in their subjects for a term of five years on a salary of Rs. 500 per month: Prof. Abanindranath Tagore (Indian Fine Arts), Prof. Sunitikumar Chatterjee (Phonetics), Prof. Meghnad Saha (Physics), Prof. Jnanendranath Mookerjee (Chemistry), and Prof. Nagendra nath Ganguli (Agriculture). Only Ganguli had a B.Sc. degree, but of University of Illinois. There were probably other factors behind his selection.

### Sir Chandrasekhara Venkata Raman

Sir Asutosh was never provincial; in his days, the university had a large number of noted professors from outside Bengal, like Raman, Agharkar, Bhandarkar, or Radhakrishnan, even some non-Indian professors, like Bruhl, Cullis, or Kramrisch [4].

The Senate minutes of January 30, 1914, show that the Vice-Chancellor and his colleagues in the Syndicate were surprised to receive the offer: "Mr. C.V. Raman who had expressed his willingness to accept the Chair was an officer in the Indian Finance Department where in the ordinary course he would draw a salary of Rs. 2000 a month. As an ardent devotee to the cause of Science he was prepared to relinquish his more lucrative appointment under the Government and to come here as a Professor of Physics at a considerable sacrifice."

The minutes of the Syndicate show that "Mr. C.V. Raman. M.A., joined his post as Palit Professor of Physics on the afternoon of July 2, 2017". The appointment was referred to the Governing Body of the Palit Endowment Trust. Palit died in October 1914 and could not see the appointment of Raman. In spite of the well-known trinity of the Physics department, C.V. Raman, S.N. Bose, and M.N. Saha, it was Raman who dominated the first sixteen years of the Department, from his joining as the Palit Professor in 1917 to his subsequent resignation in 1933, when he became the director of the Indian Institute of Science. The first twenty year period was naturally dominated by Raman, not only because of his research and his students, but also for the fact that he was holding the Palit Chair and was the Head of the Department. The result of this domination was, unfortunately, not very beneficial for the Department, in particular when the resources were meagre. Only during 1917-19 the Department had all three of Raman, S.N. Bose, and Saha as its teachers.

Raman made it clear from the very beginning that he could join only if the condition for spending two years abroad was relaxed. In spite of some objections, Asutosh made it sure that Raman did not have to go abroad and could join directly. It is an irony of fate that Raman was later removed from the Directorship of IISc for trying to rope in German professors who were fleeing Europe, like Max Born or Erwin Schroedinger.

Both Palit and Ghose Professorships started at about the same time, but the Palit Chair was always more lucrative because it carried a salary of Rs. 1000 p.m. even in those days, whereas the Ghose Professor got Rs. 500 p.m. Later, the Khaira Professorship started, but again with a smaller remuneration of Rs. 500. The Palit Professors in both Physics and Chemistry had separate laboratory funds, and could support several Ph.D. students and even tenured Assistant Professor positions out of the grant. The Palit Professor was also the ex-officio Head of the Department.

Interestingly, even after the second world war, the remuneration for the Palit Professor was only marginally better at Rs. 1300, whereas the Ghose and Khaira Professors got Rs. 750 each [5]. The hierarchy of Palit, Ghose, and Khaira Chairs was maintained for a very long time. After Raman, D.M. Bose and later Meghnad Saha occupied the Palit Chair.

Almost immediately after joining, Raman asked [6] whether he would be under any obligation to take classes, affecting his own research work. Today, such a request would have been immediately snubbed, and probably rightly so, but Sir Asutosh somehow gauged the importance of the research Raman was doing at the Indian Association for the Cultivation of Science, and the Syndicate, in the same year as Raman's appointment, resolved that Raman would be under no obligation to take classes affecting his own or his students' research work. Later, of course, Raman took classes and set question papers.

Here is an excerpt from the report Raman sent to the University about the progress of the Department in 1917:

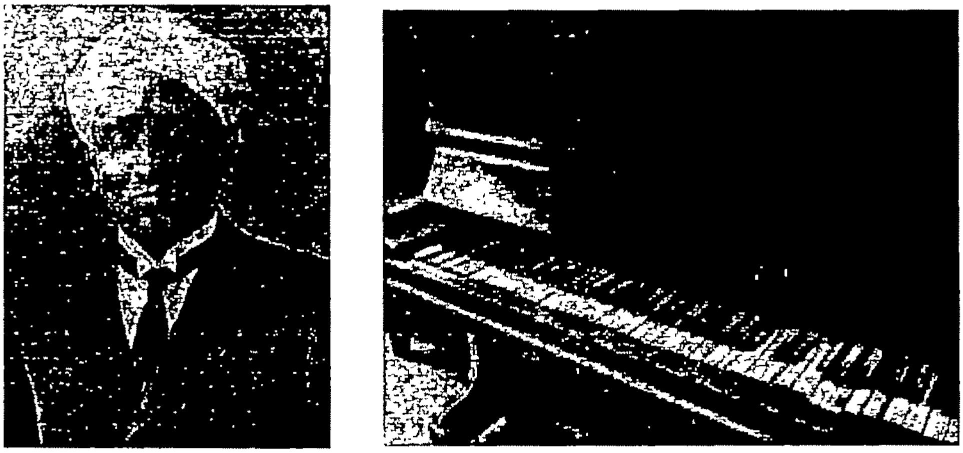
> *The department achieved very satisfactory progress during the year. Early in July, 1917, I took charge as Sir T. Palit Professor of Physics and since then have been engaged whole-time in organizing the work at the Palit Physical Laboratories and in the development of various lines of original investigation which are at present in progress. Shortly after my joining, the new scheme of University teaching came into force, by which the lecturing work has been divided between the Physics staffs of the University College of Science and of the Presidency College* [7], *and this has undoubtedly proved beneficial in enabling the members of the University staff to concentrate their attention on specialised lines of study and promises well for the efficiency of post-graduate teaching in future.*

Raman knew that successful post-graduate teaching can be done by only those who are in direct contact with research. He mentions several equipments obtained locally or from abroad to build up the laboratory. He was also effusive in the praise of the research scholars.

> *Various investigations, both theoretical and experimental, were carried out this year by myself and my pupils. The investigations ranged over the subjects of Electrical Theory, Optics, General Dynamics, and Acoustics. Three papers by myself dealing with the last-*

> *mentioned field appeared during the current year in the Philosophical Magazine, another communication in Nature, and I have also at present under preparation a lengthy monograph dealing with the mechanical theory of the violin and other bowed stringed instruments* [8]. *One of my pupils, Mr. T.K. Chinmayanandam, has this year carried out and published an investigation on the Flow of Energy in the Electromagnetic Field surrounding a perfectly reflecting cylinder. He has also carried out two other important investigations, one dealing with the application of the Quantum theory to the problem of Resonance Radiation, and another on the Diffraction of Light by an obliquely held cylinder. Mr. Sudhansukumar Banerjee has been very successful in the research work undertaken by him, and a highly interesting paper on the production of Aerial Waves by Impact written by him has been published and will also appear in the Philosophical Magazine. Mr. Banerjee has taken up another new line of work on the emission of radiation by the boundaries of diffracting apertures. A preliminary note communicated by him to Nature on the subject has been published and a more detaild account will be published shortly. [...] Mr. Sisirkumar Mitra has shown most praiseworthy activity during the current year. One of the papers on the "Asymmetry of the Illumination Curves in Oblique Diffraction" is appearing in the Philosophical Magazine, and a second paper on Sommerfeld's treatment of the Diffraction Problem is nearly ready for publication. [...] These and other activities of the new School of Physics at Calcutta have not failed to attract the attention and favourable notice of men of Science abroad, and I trust that in next year, [...] even more gratifying results will be shown.*

Raman acknowledges Sibpur Engineering College for letting his students use their laboratories. However, he was still associated with IACS, and his more interesting research works, with his more famous students like Ramanathan or Krishnan, were performed there.



Raman and the piano he bought for acoustic experiments.
This piano is still in the Department.

CALCUTTA UNIVERSITY CENTRAL LIBRARY

In 1918, Raman enlisted a number of research achievements of his group. We see that T.K. Chinmayanandam joined as Assistant Professor under the Palit grant, and P.N. Ghosh as University Lecturer. Raman and Ghosh published a paper in Nature on the "Colour and Striae in Mica". Immediately below the paper, Lord Rayleigh put a note, mentioning that this is a novel phenomena and should be investigated in detail. Ghosh was investigating this and Raman raised the issue of purchasing new equipments for the research laboratory. Sudhansukumar Banerjee, who held the joint lecturership in Physics and Applied Mathematics, got his D.Sc. and later became the Ghose Professor of Applied Mathematics in 1918.

There were 27 papers published from the Department in 1918, most of them by Raman and his group, but five by M.N. Saha (one of them was with S.N. Bose [9] "On the Effect of the Finite Volume of the Molecules on the Equation of State", published in Philosophical Magazine). Raman mentioned that more important works will get published in 1919, including "The Optical Analogue of the Whispering Gallery Problem" by Bidhubhushan Ray [10] and "some theoretical work dealing with spectral emission" by Meghnad Saha [11]. We note, with a chuckle, that in the annual report for the department, Raman spent so many words about the research of his group, but was almost silent on Saha's achievements. His tensions with Saha would be more apparent in a couple of years. In fact, he spent a full paragraph on "Babu Bepinchandra Mallik", a senior mechanic employed directly under Raman, who has shown unusual skill and devotion for the construction of research equipments.

Bidhubhushan Ray [12] was enjoying a research fellowship of Rs. 50 per month from the Palit Trust; Raman, in 1919, recommended an increase to Rs. 100 p.m. because Ray had successfully carried out an experiment on "Optical analogue of whispering gallery effect" and was then taking up research work on "Convection of radiation of heat". On the basis of the exceptional report, Ray was granted an increase for one year starting from March 1, 1919. These scholarships were always to be reviewed and renewed after every year.

In 1919 again, we see that Raman was forwarding a letter from Mr. T.K. Chinmayanandam for his resignation from Assistant Professor of Physics. He was appointed as an Assistant Professor in 1918. Raman also recommended Mr. Brajendranath Chakrabarti, a Palit research scholar, to the vacant post at a salary of Rs. 200 p.m. The Syndicate respected Raman's recommendation and Chakrabarti was appointed.

In 1921, Raman was selected as a delegate of the University of Calcutta to the Congress of Universities to be held in Oxford. The GB approved the sum of Rs. 2500 from the Trust Fund as passage money to England to enable him to attend the Congress as well as to visit other laboratories in the UK. He was also permitted by the GB of Sir Taraknath Palit Trust to deliver a course of special lectures at the invitation of Madras University in the following session and accept any renumeration that might be offered for it..

Raman was gradually getting impatient at the scarcity of funds for his research. He sent two scathing letters to the University on December 22, 1925. In the first letter, he said that the University "*has been acting in an illegal manner and that a grave breach of the trust* [Palit Trust Fund] *is involved*". The reason for his outburst was that according to the deed, "*the University shall apply the entire balance of the income of the said Trust Estate in aid of and for the better carrying out of the Trust contained in the First Trust Deed .... The First Trust Deed explicitly sets out the purposes for which the income of the endowment of Sir Taraknath Palit should be utilized, viz., the founding of the two Palit Chairs and the provision in connection with these two Chairs of suitable facilities for teaching and research.*" He further stated that the properties of Palit at 35, Ballygunge Circular Road, which were then being used for purposes "*wholly outside the expressly declared intentions of*" Palit, should be rented [13]. Even at a modest estimate, that would bring Rs. 3000 per month, which might be used for the work of the two Palit Chairs.

In the second letter, Raman said that as "*matters stand at present, practically all the resources of the University College of Science in the Department of Physics, are being utilised for the work of teaching for the M.A. and M.Sc. degrees. The great majority of the students who join these classes are those who have taken a Pass Degree in the Bachelor's Course and the work of teaching them is of a routine character. No research work at all is at present being undertaken by the M.Sc. students. The bulk of the accommodation available in the Physics Department is taken up in laboratories in which elementary work of this description is being carried on. What litle space is left has been taken up by the three Ghose and Khaira Professors. The existing workshop facilities are being entirely devoted to the work of the Ghose and Khaira Professors and to the teaching departments.*" [This may make some of us squirm a bit as if all these Professors were necessarily inferior to Raman, who was yet to discover the Raman Scattering by then.] Raman emphasized that the facilities available to the Palit Professor are miserable to the extreme: "*I have two small rooms, originally designed for work in Chemistry, as a laboratory, and research assistant on Rs. 100-10-150 and two scholars on Rs. 75 and no workshop facilities whatsoever. Under the existing constitution, all the University Professors and University Lecturers are independent of each other, and the Palit Professor of Physics has no authority whatsoever to utilize the teaching laboratories for the purpose of research, and even if he had the authority to do so, it would be impossible for him to achieve anything owing to the fact that laboratories are fully engaged with training of students in comparatively elementary work. I do not think under this circumstances it is really possible to organise and carry on the work of the Chair in a manner worthy of the intentions of the late Sir Taraknath Palit.*"

Raman then submitted his proposal for the Department to develop into a centre of research in Physics: (i) A separate building specially designed and constructed as the Palit Research Laboratory of Physics, including the residential quarter for the Director; (ii) At least three research assistants at a scale of 150-25-300 to work in different branches of Physics; (iii) At least six research scholarships of Rs. 75 per month; (iv) A specially fitted-up workshop under the control of the Palit Professor in Physics; and (v) A fixed research grant to enable him to procure and add equipments to the laboratory from time to time. A more detailed proposal was sent to the Syndicate om January 14, 1926.

The university was ready to enquire from an engineer about the feasibility of selling some of the properties of 35, Ballygunge Circular Road, and what a fair rental should be for those properties if they cannot be sold. The University and the GB for the Palit Trust fought a lot over what the rent should be. The Syndicate requested the GB to take Rs. 6000 per annum, the GB refused and asked for Rs. 15000. There were some arguments but ultimately, in the latter years, the University was paying Rs. 10000 per year as the rental.

We find no response to the later letters.

Raman, in 1926, requested for Rs. 10000 to be utilized in testing the correctness of Einstein's Theory of Relativity, "which has been called in question by Professor Miller, President of American Physical Society". The GB of Palit Fund recommended that the money be made out of the General Fund of the University. The Syndicate sent it to the Board of Accounts. Raman received a much reduced amount. It is not sure what happened to that experiment.

It appears that the Palit Professor enjoyed considerable independence even in administrative matters. For example, the Syndicate, in a meeting on May 27, 1918 confirmed appointment of one Patitchandra Roy on probation for six months as clerk and storekeeper at a monthly salary of Rs. 40 with effect form February 1, 1918. The same meeting also approved the recommendation of Raman to award Palit Research Scholarship of Rs. 100 to Brajendranath Chakrabarti [14]. However, the discussion on another recommendation for Raman to award Palit Research Scholarship to Ghose Research Scholar Bijaykumar Basak was postponed.

Raman had been invited to a number of places in India and abroad, mostly for giving lectures, and the Syndicate always approved that. For example, in 1920 he was invited by Punjab University, Lahore, to deliver a course of 15 lectures on an honorarium of Rs. 1500.

In 1924, Raman was offered a University Readership in Science by the Patna University for the session 1924-25 to deliver a course of lectures for an honorarium of Rs. 600 and other allowances. The Syndicate approved. Raman authorized S.K. Mitra to sign the scholarship and salary bills during his absence from Calcutta.

Raman was appointed on the Special Committee of Enquiry to report on the Indian Institute of Science by the Ministry of Industries, Government of India from November 10, 1921. Raman offered to place the honorarium of Rs. 50 per day that he would get at the disposal of the University. The Syndicate resolved that the sum mentioned be used as a special research grant of Raman. The Enquiry concluded on December 23, 1921, when Raman was again placed at the disposal of the University. Accordingly, he placed a sum of Rs. 2100 with the University.

Next year, Raman was invited to attend the Bi-Centenary of the Academy of Science in Russia. He requested a grant of Rs. 2500 from the Palit Fund. The GB resolved that while it would welcome his visit, the terms of the Palit Trusts did not permit such a grant. However, the Syndicate stepped in and provided the money from the funds of the University. He was also requested to visit some other Universities in continental Europe.

A four months deputation to Europe for Raman was approved from September to December, 1929. Palit Trust also approved Rs. 4000 as his passage money. The trust also sanctioned Rs. 3000 for Raman's research.

In 1931, Raman was placed on a special deputation to Europe from March 1 to June 30 to attend International Congress of Pure and Applied Chemistry, Madrid, and to visit and lecture at other European universities. At that time, Raman's salary was Rs. 1500 per month.

At the initiative of Raman, Arnold Sommerfeld, who was to travel via Bombay to Japan in 1928, was invited to deliver a course of Readership Lectures at an honorarium of Rs. 2000. He was awarded the Honorary D.Sc. of the University of Calcutta on December 12, 1928. He delivered a course of lectures on Wave Mechanics from October 4 to October 26, 1928. R. Singh and F. Riess have already published on the Raman-Sommerfeld correspondence (Curr. Sci. 74, 1112 (1998)), copies of the cable to Sommerfeld from Raman and the script of letter from Sommerfeld accepting the invitation. Raman arranged for the lectures to be taken in verbatim. They were printed in a book form by the University Press.

The Government of India, in 1926, was considering a grant to the Indian Association for the Cultivation of Science. The Secretary to the Government of Bengal, Department of Education, wrote to the University of Calcutta inquiring whether the activities of Raman as the Honorary Secretary of the Association clashed with his ordinary duties of Professor. The Syndicate replied in the negative.

Raman left on April 1, 1933. He was granted a leave without pay for fourteen months by the University, to accept the appointment as the Director of Indian Institute of Science. In 1935, he resigned from the Council of Fellows of the University.

## The Nobel Prize

Raman got D.Sc. *Honoris Causa* from CU in 1921, and later honorary Ph.D. from the Universities of Freiburg, Paris, and Dhaka, the last two after he got the Nobel Prize in 1930. In 1930, he was also awarded the Hughes Medal, which was presented in 1931 by the Governor of Bengal. In 1931, he was awarded the LL.D. degree of the University of Bombay at a special convocation and delivered lectures.

By 1928, Raman has made his famous discovery and congratulations were pouring in from various places. Extracts of some of the letters were forwarded by Raman to the Palit Trusr. The Syndicate meeting on August 10, 1928 recorded the following proceedings of the GB of the Palit Trust held on August 2, 1928:

"Read a letter from Professor C.V. Raman forwarding the following extract from a letter, dated the 16th June, 1928, addressed to him by Professor Arnold Sommerield of Munich, one of the greatest living Physicists:-

> *"Your papers on the optical analogue of the Compton Effect formed the subject of a lecture which I gave in our colloquium at Munich. At the same time I showed slides of some very beautiful photographs of your effect taken by Professor Pringsheim at Berlin. We are all of us full of enthusiasm on this great result. Japan, that has for a longer time worked in Modern Physics, has nothing to show comparable with this discovery."*

Read also a letter from Professor C.V. Raman forwarding the following copy of a letter addressed to him by Professor Siegbahn, the eminent Swedish Physicist and Nobel Laureate regarding his new discovery:

> *"My dear Professor Raman,*
>
> *I had the great pleasure some time ago of receiving your interesting address on a New Radiation, and to-day I got the second paper about the same subject. Of course I have been studying those with great interest and it seems to me that specially in the second paper you have given a very convincing evidence of the reality fo the new phenomenon. It is indeed a wonderful discovery you have made, and I wish to send you my most hearty congratulations, on these beautiful scientific results.*
>
> I am.
> With sincerest regards,
> Yours sincerely
> *Mann Siegbahn*"

The Nobel Prize came in 1930. We note that Siegbahn was among those who proposed Raman's name for the prize.

On November 14, 1930, the Syndicate resolved: "*The Vice-Chancellor and Syndicate of the Calcutta University convey to Sir Chandrasekhara Venkata Raman Kt., F.S., M.A., D.Sc., Ph.D. (Freiburg), N.L.. their cordial congratulations on the award of the Nobel Prize in fitting recognition of his great contributions to the cause of advancement of scientific learning. The Syndicate rejoice to find that a Professor of this University is the first recipient in Asia of the Nobel Prize in Science.*"

Raman was placed on special deputation for the period of November 15, 1930 to the end of Februaruy 1931 to enable him to visit important scientific centres in Europe. His salary from November 1930 to January 1931 was paid in advance. University offices were closed on November 21, 1930 in honour of the Nobel Prize to Raman.

### Debendramohan Bose

Debendramohan Bose, M.A. B.Sc., was appointed the Rashbehary Ghose Professor in 1914 [15]. So, to be precise, Bose was the first appointee to the Department. But under the rules of the endowment, he was supposed to spend the first two years of his seven-year tenure in a university outside British India. He went to the Humboldt University in Berlin but due to the outbreak of the war, asked for permission to leave Germany and join some university in either England or

Switzerland. (Agharkar had been interned by the authorities in Berlin.) This was not entertained. Bose used to send reports of his progress to the University from time to time, and came back in 1919 after obtaining his Ph.D. with Erich Regener.

Before leaving, Bose asked for the passage money to Europe. It was turned down by the Board of Management for the Rashbehary Ghose Endowment [16], mentioning that the salary had been fixed at a high value of Rs. 500 so that the passage money should be paid from it. Still, it recommended an advance of Rs. 500, to be deducted later in 5 equal instalments. He had to give an undertaking in writing that he would not resign the Professorship within three years after his return from the foreign University, and was infomed that he was expected to proceed to doctorate.

Bose ultimately joined the Department on July 14, 1919, completing his Ph.D. He brought a number of new German books which were not available in India. He gave two of them, Thermodynamik and Warmestrahlung, both by Planck, to his junior colleague S.N. Bose. This made Satyendranath interested towards Planck's hypothesis and led to a dissatisfaction with Planck's deduction of radiation formula.

Bose's term as Ghose Professor was going to end on March 23, 1921, and he was re-appointed by the Management Board of Ghose Trust.

In 1925, Bose requested the Dean of the Faculty of Science, Allahabad University for a loan of an X-ray spectrometer which was lying idle in the laboratory of Allahabad University for a period of six months. The Registrar of Allahabad University agreed in principle if the request officially comes from the University of Calcutta, but with three conditions: (i) The instrument would not be removed anywhere else outside the laboratory; (ii) CU would be responsible for all possible damages; (iii) Transit and other incidental charges would have to be borne by CU. The syndicate agreed and the Registrar was asked to sent a letter to AU.

Bose applied, in 1926, for a leave without pay for a period of two years to join the post of Professor of Physics in Dacca University. The Board of Management of Ghose Endowment recommended to the Syndicate to approve the leave on November 18, 1926, and the Syndicate approved on January 7, and again rcommended on January 21. The next meeting on February 4 recorded a letter from Bose withdrawing the application. We know that S.N. Bose was finally appointed to this post..

Ghose Travelling Fellowship for the year 1927-28 was awarded to Bose. He proposed to travel to laboratories of Siegbahn in Upsala, Bohr in Copenhagen [17], to Göttingen, Berlin, Vienna and also to attend the Volta Centenary Celebration at Como where he had been invited to attend. This was finally approved by the Syndicate on July 12, 1927. Bose left on the first week of August.

On July 22, following a letter from D.M. Bose, Syndicate resolved that the salary for July, fees for setting papers and for examining answer scripts and the first half yearly instalment of Ghose Travelling Fund (Rs. 2500) be paid to him before his departure.

In his later years in the University, Bose worked on magnetism, X-rays, and Raman scattering. His group found some interesting relations between magnetic fields and viscous properties of liquids.

Bose resigned from the University and joined Bose Institute as the Director in 1938. His most celebrated work, that with Biva Choudhuri, on the tracking of mesons on halftone emulsion plates, and recognised by Powell as the first of its kind in the world, was done from there.

D.M. Bose

P.N. Ghosh

S.N. Bose

**Phanindranath Ghosh**

P.N. Ghosh was appointed a Lecturer of Physics in 1916. In 1920, he got his Ph.D. on "The Colours of the Striae in Mica and other optical investigations", and joined as the Ghose Professor of Applied Physics on December 10, 1920. He asked for a deputation to England and America to visit some "important centres of technological study" there. The decision was approved on December 23, 1920, and he was allowed to visit Europe and America in 1921 for two years to learn Glass Technology and Metal Engineering; he was also given a travelling allowance of Rs. 3000. He came back from Europe and joined again on November 27, 1922.

In 1924, we find that Ghosh was buying machines for workshop. It appears that the Department of Applied Physics is already set up (although without a formal approval as yet); his purchases were meant for the Department of Applied Physics. In its meeting on July 26, 1924, the Syndicate requested the Governing Body of the University College of Science to appoint standing committees for the Departments of Applied Physics and Applied Chemistry.

The Senate resolution to approve the Department of Applied Physics was taken on April 15, 1930.

**Satyendranath Bose**

Bose, along with M.N. Saha and Abinaschandra Saha, was selected as a Palit Research Fellow in 1916, at a monthly emolument of Rs. 200. He taught and set questions in both Physics and

Applied Mathematics, and in April 1919 we see his name in the list of Lecturers in the Physics Department, with a salary of Rs. 225 at the end of 1919. Thus, it is reasonable to assume that he joined as a Lecturer in 1918. Saha also joined as a Lecturer in the same year but in the Applied Mathematics Department; he shifted to Physics in 1919. Bose left for Dacca in 1921; in this brief period, he published a paper with Saha on the equation of state of a real gas, and translated, again with Saha, the original papers of Einstein and Minkowski from German to English. Saha knew passable German, Bose had to learn German for this. The book was entitled *The Principle of Relativity : Original Papers by A. Einstein and H. Minkowski, translated into English by M.N. Saha and S.N. Bose with a historical introduction by P.C. Mahalanobis,* and published from the CU Press. The following articles were there:

*Historical Introduction* [By Mr. P.C. Mahalanobis]

*On the Electrodynamics of Moving Bodies* [Einstein's first paper on the restricted (Special) Theory of Relativity, originally published in the Annalen der Physik in 1905. Translated from the original German by Dr. Meghnad Saha]

*Albert Einstein* [A short biographical note by Dr. Meghnad Saha]

*Principle of Relativity* [H. Minkowski's original paper on the restricted Principle of Relativity first published in 1909. Translated from the original German by Dr. Meghnad Saha]

*Appendix to the above by H. Minkowski* [Translated by Dr. Meghnad Saha]

*The Foundation of the Generalized Theory of Relativity* [A. Einstein's second paper on the Generalised Principle first published in 1916. Translated from the original German by Mr. Satyendra Nath Bose]

*Notes*

## Meghnad Saha

Saha was the first teacher of the Department with a doctorate (even Raman did not have one; he got an honorary D.Sc. later). The Syndicate in a meeting held on October 4-5, 1918 suggested the following Board of Examiners for the D.Sc. thesis "On the fundamental law of electrical action": Prof. O.W. Richardson, Prof. A.W. Porter, and Dr. N.R. Campbell.

On November 28, the Syndicate agreed to the request of Saha to forward some additional work of his to the examiners.

Porter agreed to examine the D.Sc. thesis. Campbell regretted but sent his suggestion of a list of examiners, after consulting Richardson. The names are: A.S. Eddington, W. Wilson, J.A. Cunningham, and L. Silberstein. The syndicate decided to ask Eddington to be the second examiner. Campbell later wrote that Eddington was away and would not be back before July 1919 (the expedition to get the shift of light during the eclipse), so Cunningham should be appointed as an examiner to avoid delay. This was approved by the syndicate. The sysndicate received the reports and granted the D.Sc. on July 26, 1919.

In 1920, he went to Germany and four of his most celebrated papers were published between October 1920 and May 1921, three in Philosophical Magazine and one in Monthly Notices of the Royal Society. It can arguably be said that modern astrophysics started with the Heat Ionisation formula of Saha; see the article on Saha and Russell in this volume.

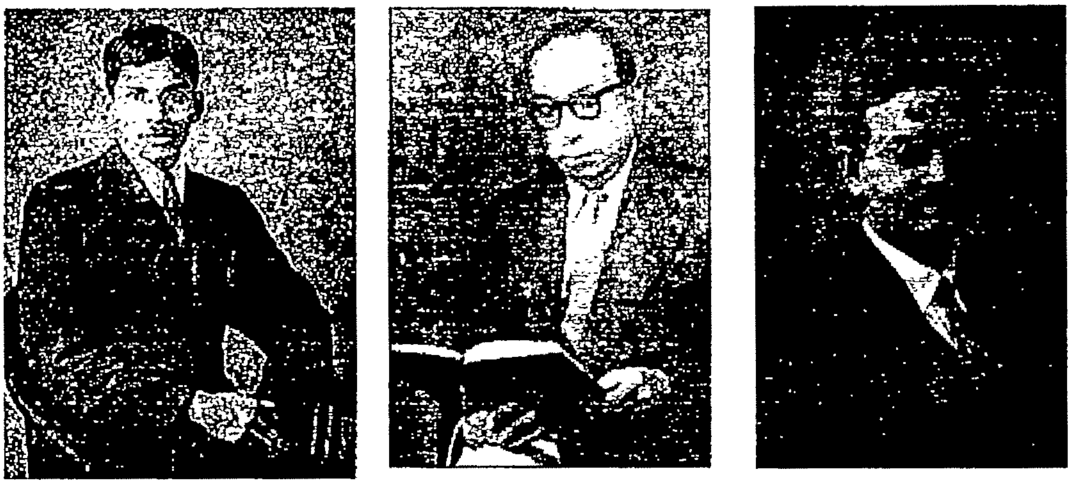
He joined as the Guruprasad Singh Professor, which is commonly known as the Khaira Professor, on November 7, 1921. The Deputy Secretary of the Government of Bengal conveyed the sanction of the Government on his appointment to that Chair, which was read in Syndicate meeting of November 10, 1921. The other Khaira Profesors, whose appointments were also sanctioned were Jnanendranath Mukherjee and Sunitikumar Chatterjee. Saha got a passage money of Rs. 1640 from the Guruprasanna Ghose Legacy Trust of the University for coming back from Berlin.

In 1922, 180 pounds were sanctioned to him out of the Khaira Fund for purchasing equipments. In that year, Saha requested for a room in the Science College to be allotted to him. The Vice-Chancellor was requested to take necessary action in the matter. It appears that the conflict between Saha and Raman had already started; Raman wrote to the University that Saha had made misleading statements regarding the allotment of the room. Again the VC was requested to look into the matter.

Saha had an offer from Banaras Hindu University in 1923. In a letter to the VC dated June 26, 1923, he informed that he had been offered the Chair of Physics at BHU on a salary of Rs. 750-50-1000 plus many other advantages for continuing his research work. He said that he was willing to continue to serve his Alma Mater provided the University grants him a graded scale of pay of 650-50-1000 and Rs. 15000 immediately as personal research grant. He wrote that he has only a week to consider the offer. The Syndicate replied that in view of the financial position of the University and in view of the claims of other University teachers, his request could not be complied with.

Though Saha did not accept the offer from BHU, he soon resigned from the Khaira Professorship to join Allahabad University at the scale of 800-50-1250, which was considerably higher than his pay of Rs. 500 at CU. His letter is reproduced in full in the minutes. He wanted to resign from September 17, 1923 in a letter dated September 11. The Syndicate, in a meeting on September 14, referred the letter to Board of Management for the Khaira Fund. The Khaira fund Board met on September 20, accepted the resignation, and in the same meeting appointed Sisirkumar Mitra, then a Lecturer, as the Khaira Professor at the scale Rs. 500 and house allowance of Rs. 100 after considering his qualifications. After his resignation, the two rooms allotted to him was taken over by P.N. Ghosh on September 1923. Later that year, Saha wrote for use of certain scientific equipments which he had brought on behalf of the University in Allahabad under any term the University might dictate. The syndicate regretted.

We will not see Saha again till 1938 when he came back as the Palit Professor, after the Chair fell vacant when D.M. Bose moved out to Bose Institute [18]. Of course, he was appointed as a member of the selection committee to select the Khaira Professor twice; the first time it went to S.K. Mitra, and the second time to B.B. Ray.



M.N. Saha S.K. Mitra B.B. Ray

The self-portrait of B.B. Ray was signed and presented to Niels Bohr
(Courtesy: Niels Bohr archive)

### Sisirkumar Mitra

Sisirkumar Mitra was one of the first research scholars of the Department; the Governing Body of the Palit Endowment offered the Sir Taraknath Palit Research Scholarship in Physics of Rs. 100 per month to him in 1914. He was inducted in Raman's group when the latter joined, and we have seen, from the notes of Raman, how even in 1917 he was publishing papers in top quality journals. He was also taking M.Sc. classes in 1917. We find his name in the list of University Lecturers in 1919, with a monthly salary of Rs. 225.

He got D.Sc. in 1920. In 1923, he was appointed the Khaira Professor of Physics, after Saha left. At that time, he was in Europe as Rashbehary Travelling Fellow. He requested that he be allowed to change his plans submitted earlier to enable him to work on Radioactivity at the Institut de Radium in Paris in the Laboratory of Marie Curie. This was approved by the Syndicate. After coming back, he initiated the teaching of wireless technology to postgraduate students, and established the Wireless Laboratory and a radio transmitting station in 1925. This was the seed of the Radiophysics and Electronics Department.

In 1935, we see that his group carried out extensive investigations on the properties of the ionosphere in the Wireless Laboratory of Science College. For the first time, they found experimental evidence on the connection between the low-lying D layer of the ionosphere and the presence of ozone in upper air. Mitra got a Ghose Travelling Fellowship in 1935. Moree details about Mitra's work is available elsewhere in this volume.

**Bidhubhushan Ray**

We first met B.B. Ray as a research scholar working with Raman, and his works on the optical analogue of the whispering gallery effect was acclaimed by Raman himself. He later joined as an Assistant Professor to the Palit Chair in 1921, and later raised to a substantive post of University Lecturer.

Bidhubhushan Ray was awarded D.Sc. in 1923, based on five papers, one of them with Raman. In the same year, Ray was awarded the Palit Foreign Scholarship of Rs. 5000 per annum for two years. At his request, a clause was included in the bond that if on return, Ray served the University for five years, the bond would not be enforced. A amount of Rs. 2000 was paid out of the Scholarship fund to enable him to buy outfit and passage money to Sweden. He worked with M Siegbahn in Upsala (1923-24) and Niels Bohr in Copenhagen (1924-26) on X-ray emission lines, and founded the school of X-ray spectroscopy in India. He got very strong recommendations from Bohr as to his ability as an X-ray crystallographer but apparently the university did not help him much to set up his own laboratory. The GB of the Palit Trust recommended to the Council for Post Graduate Teaching in Science that Ray be appointed as a Lecturer in the Department of Physics at an initial salary of not less than Rs. 200 a month. He was offered a Lecturership, which he accepted.

Ray was also offered a readership in Physics in the Dacca University in 1928. He wrote to the University for leave withut pay for two years. He also wrote that the salary of Rs. 375, which he was then drawing, was inadequate to clear the debts incurred for availing Palit Foreign Fellowship. The Executive Committee of the Council of Post-Graduate Teaching in Science resolved that in the interests of the University, the services of Ray could not be spared. They recommended that he be given a special increment of Rs. 50 to his monthly salary from January 1, 1928. The Board of Accounts resolved that the special increment might be given provided that a vacant post in the Department of Applied Mathematics was not filled up. He got the Ghose Travelling Fellowship in 1933.

In 1935, The Khaira Chair in Physics fell vacant as S.K. Mitra was appointed as the Ghose Professor, which again fell vacant because of the resignation of D.M. Bose who moved to the Palit Chair (note the hierarchy among the chairs). The selection committee for the Khaira Professor included J.C. Bose, S.N. Bose, and M.N. Saha. The selection took place on February 18, 1935. J.C. Bose and M.N. Saha were present; S.N. Bose could not come but sent his opinions. B.B. Ray was selected at a salary of Rs. 750 p.m.; no probationary period was needed as he already served the Department for a long time. The sanction from the Government came on April 4 and Ray joined as Khaira Professor of Physics on April 6, a post he occupied till his untimely death in 1944.

He started building up his laboratory immediately, asking for about Rs. 4000 from the University in early 1936, to procure some high tension DC equipments, an electron diffraction camera, and accessories. In August 1936, Sudhirranjan Das and Sukhendubikas Chaudhuri joined as his Ph.D. students with a monthly salary of Rs. 50 each.

Rajinder Singh and Falk Riess wrote a very informative article on B.B. Ray and his contributions in Current Science 75, 965 (1998).

### Other Teachers of the Department

Jogeschandra Mukherjee and Phanindranath Ghosh joined as Assistant Professors (sometimes called Lecturers) in 1916, in a scale of 200-25-500. They were the first teachers of the department, as Raman was yet to join and D.M. Bose was away in Germany. Susilkumar Acharyya and Abinaschandra Saha joined in 1917, again as Assistant Professors. At the end of 1919, we see that Mukherjee and Ghosh were getting a monthly salary of Rs. 250 each, while Acharyya, Saha, and three other teachers were at Rs. 225. These three teachers were Satyendranath Bose, Meghnad Saha, and Sisirkumar Mitra. The next appointee to the Assistant Professor level was Durgadas Banerjee, followed by Hrishikes Rakshit, who later moved to the Radiophysics department.

There were several Assistant Palit Professors, who took classes in the department but were not regular members of the University. They used to enjoy a graded scale from the Palit Fund and were more or less like modern postdoctoral fellows or research associates. Brajendranath Chakrabarti was one of them; he was later absorbed as a University Lecturer. Bidhubhushan Ray was also appointed an Assistant Professor and later absorbed as a regular teacher. In 1921, the University Gold Medalist Sasibhushan Mali joined as an Assistant Professor in the grade 100-25-200 in place of Durgadas Banerjee [19]. People like T.K. Chinmayanandam and Bhabanath Banerjee resigned after one or two years. Sudhansukumar Banerjee held a joint Lecturership position in Physics and Applied Mathematics. He took regular classes in Physics, but was later appointed, after he got his D.Sc. from Raman's laboratory, as the Ghose Professor of Applied Mathematics when Ganesh Prasad resigned.

In 1921, the GB of the Palit Trust approved a request from Brajendranath Chakrabarti, Assistant to the Professor of Physics, that his salary be placed in a graded scale and placed his salary in the scale 200-25-300 and the first increment was approved from June 1, 1921. Later it was clarified that he was an Assistant Professor, and not assistant to the Professor as noted. The clerical mistake was corrected by the Syndicate. He got his D.Sc. in 1922; his examiners were C.V. Boys, A.W. Porter, and L.N.G. Filon.

The appointment of Brajendranath Chakrabarti was to expire on May 31, 1925. His salary was being paid out of the Palit Fund. He applied to the GB of the Trust for appointment on a "more handsome scale of pay". His monthly salary at that point was Rs. 300 in the scale of Rs. 200-25-300. The GB of the Trust resolved that it was not possible to renew the appointment, without giving any reason. The application was referred to the Council of Post Graduate Teaching in Science. In fact, a number of University teachers were facing termination of service on May 31, 1925.

The Syndicate resolved, following the motion by Syamaprasad Mookerjee in the Senate, that the services of the teachers in the post-graduate departments that are going to be terminated on May 31, 1925, be extended for four months from June 1, 1925, and for any subsequent increments, the latter was to be taken as the appointment date. Chakrabarty was subsequently absorbed as a Lecturer, and his position was made permanent in 1932.

Hrishikes Rakshit joined as a Lecturer in 1935.

## Research Scholars

The research scholarships were payable mostly from the endowment funds. The initial salary was Rs. 50, or later, Rs. 75, the position being something like a Junior Research Fellow today. The scholars progressed to Research Assistants and later to Assistant Professors. The Assistant Professors were tenured, but with a graded pay, and they used to teach in the M.Sc. course.

A number of research scholars, at that time, were associated with some laboratory but did their independent work towards a D.Sc. A few notable names, during the first 20 years, are those of Meghnad Saha, Bidhubhushan Ray, Sisirkumar Mitra, Brajendranath Chakrabarti, J.C. Kamesvara Rao, Durgadas Banerjee, Debiprasad Raychaudhuri, Hrishikes Rakshit, Sasibhushan Mali, P.C. Mahanti, Kedareswar Banerjee, and Sukumar Sarkar. Banerjee, one of the leading X-ray crystallographers of his time, determined the molecular structures of naphthalene and anthracene during graduate student days, and later became Director of IACS. Raychaudhuri was a famous teacher and a pioneer in writing textbooks in Bengali. Rakshit shifted to the Department of Radiophysics later, and Mahanti to the Department of Applied Physics. Mali joined Dacca University in 1922 [20]. Raychaudhuri and Sarkar joined as honorary teachers in 1935.

There was an interesting episode about K.R. Ramanathan, an M.A. of the Madras University and working with Raman, whom the latter recommended to be allowed to submit his D.Sc. thesis form the University of Calcutta. The Syndicate declined as the conditions of M.A. degree of Madras University were different from those of the Calcutta University. Ramanathan later obtained the first D.Sc. degree from Madras University, and became the first Director of Physical Research Laboratory, Ahmedabad.

P.N. Ghosh was one of the early Ph.D.s of the Department; he was awarded in 1920. We find names of several other recipients of research fellowships, but not all of them may have joined. The records show Susilkumar Acharyya and Kumarnath Banerjee as the first recipients of Rashbehary Ghose Research Scholarship of Rs. 75 per month in 1914. Acharyya was one of the early teachers of the Department too. They and S.K. Mitra were the first research scholars of the Department.

In 1917, Bijoykumar Basak, who passed the M.Sc. examination from Presidency college in 1916 with first class (rank 2nd), asked for a research scholarship from CU. It was again approved from the Ghose Fund, effective from February 1, 1917. Such scholarships were also awarded in Chemistry and Mathematics. Later, the scholarship positions were advertised on condition that the students will work full time for at least 2 years.

Among the other research scholars in the first 20 years, we find names like J.C. Kamesvara Rao, Goverdhanlal Datta, Susilkumar Datta, L.A. Ramdas [21], Narayanchandra Majumdar, Kedareswar Banerjee, Durgaprasanna Acharya, Sukumarchandra Sarkar, Amarendranath Banerjee, Rakhahari Baksi, Baidyanath Mukherjee, Jagattaran Dhar, Syamadas Chatterjee, Purnachandra Mookerjee, Manindramohan Deb (supported by Palit Trust), Satyendrakumar Ghosh, Kshetramohan Basu, Nripendranath Majumdar, Haraprasad De, Sudhirkumar Datta, Ramanimohan Mukherjee, Harigopal Bhar, Susobhan Datta, Pramodakumar Raha, Debiprasad Raychaudhuri, Binodbihari Dutt [22], Atulchandra Ghosh, Jatindranath Bhar (supported by Ghose Trust), Radhaballabh Karmakar, Sudhirchandra Roy [23], Atulkrishna Chatterjee, Bhabanicharan Sil, Sukhendubikas Chaudhuri, Premtosh Shyam [24], Sudhirranjan Das (supported by Khaira Trust). Hrishikes Rakshit held a University fellowship, starting from 1930.

Jatindranath Set was an assistant to the Palit Professor; he was arrested under the Defence of India act on July 14, 1916.

Research and teaching in Physics was a field completely dominated by men in that era; Purnima Sinha (née Sengupta) was the first lady to submit his Ph.D. thesis in 1955. Parongama Sen is the first lady teacher of the Department.

Foreign travels were funded for research scholars and assistant professors. In 1918, Snehamoy Datta was awarded a Palit research Scholarship of Rs 3000 per annum and passage money of Rs. 1000 to study in London. He did his D.Sc. From London University In spectroscopy, taught in Presidency College, Rajshahi College, became the DPI of undivided Bengal and finally served as the Registrar of the University of Calcutta. He was an INSA fellow. Debiprasad Raychaudhuri got Rs. 10000 tenable for three years as Palit Foreign Scholarship in 1931.

Not all funding requests were granted. Satisranjan Khastagir, who was working in Edinburgh, applied for Palit Foreign Scholarship in 1922, but it was not awarded. He applied again in 1923 but was refused. Brajendranath Chakrabarti requested for travelling allowance to travel to Bangalore to attend the Science Congress in January 1924; there was no provision in the budget, and the Syndicate asked Raman to check with D.P.I. Bengal to see if the Government had any such provisions.

## Post-graduate Teaching

A joint meeting of the GB of Palit Endowment and Board of Management of Ghose Endowment was held on May 16, 1916. The proceedings were placed in the Syndicate on May 19. A previous Joint meeting on May 11, 1916 had appointed a subcommittee to draw up a scheme for the work of the University College of Science during that and the next sessions. The subcommittee consisted of Asutosh Mookerjee, Mahendranath Ray, P.C. Ray, P.C. Mitter and P. Bruhl. The subcommittee's recommendations with respect to Physics were as follows:

> *A fifth year* [25] *M.A. and M.Sc. class be opened for Physics and the number of students be limited to twelve. They will be equally divided among General Properties and Sound, Light and Heat.*

Thus, the formal teaching started from 1916, when two lecturers also joined. We find that in 1919, there was also a "research group" in the M.Sc. Physics curriculum. Sasankasekhar Mukherjee stood first in it and asked for a research fellowship, which was referred to the Palit and Ghose Trusts.

Even in 1917, we see a formidable list of teachers in the post-graduate course of Physics. There are 13 names, alphabetically: Susilkumar Acharyya, Sudhansukumar Banerjee, Charu chandra Bhattacharyya, Satyendranath Bose, Phanindranath Ghosh, P.C. Mahalanobis, Dwijendrakumar Majumdar, D.B. Meek, Sisirkumar Mitra, Jogeschandra Mookerjee, C.V. Raman, Abinaschandra Saha, and Meghnad Saha. Some of them, like Bhattacharyya, Meek, Majumdar, and Mahalanobis were in the Presidency College, some like S.N. Bose, M.N. Saha, S.K. Mitra, S.K. Acharyya, A.C. Saha and S.K. Banerjee were research scholars or assistant professors of the Physics Department. Raman, Ghosh, and Mukherjee were regular teachers of the Department. S.N. Bose and M.N. Saha took classes in the Applied Mathematics Department too.

In 1918, a number of electrical, optical, and acoustic equipments were procured or constructed for the M.Sc. Teaching laboratory, and Raman personally supervised the building of the workshop. The post-graduate teaching included: Abinaschandra Saha for Electrical laboratory; P.N. Ghosh and S.K. Mitra for Optics group; Susilkumar Acharyya and Meghnad Saha for Heat and Thermodynamics; J.C. Mukherjee for Acoustics; S.K. Banerjee on General Physics; T.K. Chinmayanandam and S.N. Bose on General Physics practical. Raman mentiond that this is a temporary arrangement until "Mr. Chinmayanandam, whose position at present is that of an Assistant Professor, is also appointed as a University Lecturer by the Senate".

The first M.Sc. examination for the CU students was held in August 1917. 17 students were from Presidency College, 5 from the University, and 4 were non-collegiate students. People like Brajendranath Chakrabarti and Durgadas Banerjee got first class from Presidency College; P.N. Ghosh got a second class. In 1918, there were 8 students from CU out of which 4 passed. This gradually went up to 11 out of 18 in 1936.

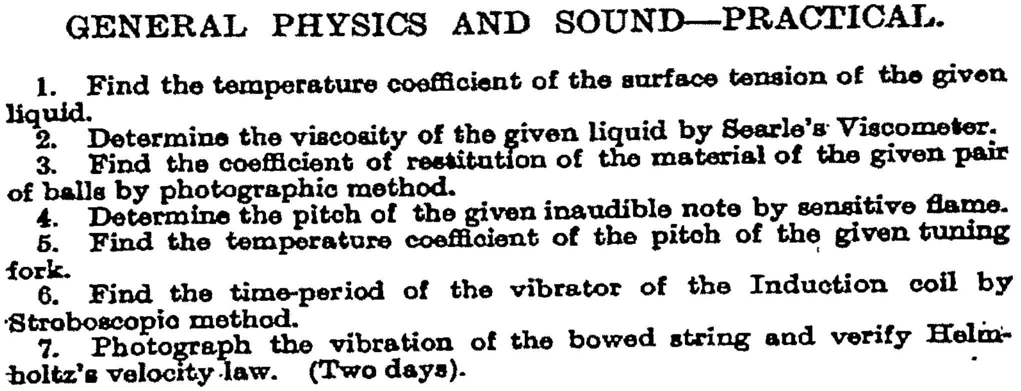
## Some Old Question Papers from the Archive

The first M.Sc. lectures in CU were given in 1916. There were no fixed textbooks. As far as we can gather, some standard British textbooks might have been used, but teachers also introduced new ideas to the students from research papers as a part of the course.

The first question papers that we can get hold of, with CU teachers as paper setters, are from 1918. There are two compulsory theoretical papers on Electricity and Magnetism; the first paper was set by D.B. Meek (of Presidency College) and Susilkumar Acharyya; the second paper by W.A. Jenkins (from PC) and Abinaschandra Saha. The first paper consists of questions that we now mostly study at the undergraduate level. In the second paper, radioactivity and X-ray are included. There is even a question on the characteristic X-ray lines of Nickel. One may note that Moseley's law was only five years old at that time.

There were three groups for Papers III and IV. One was General Physics (set by Sudhansukumar Banerjee and Satyendranath Bose—the spelling used was "Basu"—and as far as we know, this was the first paper set by Bose [26]) and Sound (set by Jogesh Mukherjee and Charuchandra Bhattacharyya of PC). The questions set by Banerjee and Bose were mostly from Classical Mechanics and General Properties of Matter. The second group was on Light. The two papers were set by P.N. Ghosh and P.C. Mahalanobis, and S.K. Mitra and D.K. Majumdar. The second paper also included the theory of relativity. There are questions like:

> *How can you find out the temperature of the Sun by observing the spectral distribution of energy in sunlight?*
>
> *What is Balmer series? How can it be explained by Bohr's atomic model*
>
> *Write an essay on the development of the theory of relativity.*



GENERAL PHYSICS AND SOUND—PRACTICAL.

1. Find the temperature coefficient of the surface tension of the given liquid.
2. Determine the viscosity of the given liquid by Searle's Viscometer.
3. Find the coefficient of restitution of the material of the given pair of balls by photographic method.
4. Determine the pitch of the given inaudible note by sensitive flame.
5. Find the temperature coefficient of the pitch of the given tuning fork.
6. Find the time-period of the vibrator of the Induction coil by Stroboscopic method.
7. Photograph the vibration of the bowed string and verify Helmholtz's velocity law. (Two days).

Fig. 1: The M.Sc. level experiments as they were in 1918.

The third group was Heat. Papet III was set by S.N. Maitra and C.V. Raman, and paper IV by M.N. Saha and D.N. Mallik, which is actually on Thermodynamics.

In 1921, we see that some of the papers are now set by one examiner only; either from CU or PC. In paper 2, there was a question:

> *Deduce Rutherford's formula for the scattering of alpha particles by matter. How has this formula been experimentally verified for different elements?*

Note that it was still the days of the old quantum theory. However, General Relativity has already burst upon the scene of Physics and experimentally verified by Eddington in 1919. Within two years, we see a question set by P.C. Mahalanobis:

> *Explain the fundamental principles of the generalised (gravitational) theory of relativity and give a short account of the evidence in favour of this theory.*

Of course, the first English translation of Einstein's work was already done by Bose and Saha and published from the CU Press. This could have been used as a textbook.

The three groups were still there. Although Bose was setting questions in General Physics and Sound, they were still based on 19th century physics. B.B. Ray appears as a paper setter for the Light group. This paper consisted of questions from Geometrical and Physical Optics. In the second paper on Light, we see questions on electromagnetic theory and the Bohr model in the parts set by D.M. Bose, and on Zeeman effect and its effect on astronomy in the part set by B.N. Chakrabarti. If the papers were set by teachers who taught that part, S.N. Bose and D.M. Bose taught Thermodynamics in 1920-21, including topics like the specific heat of solids and the current theories by Einstein and Debye (the Debye model came in 1912).

In 1922, we find questions on the Bohr-Rutherford model in Paper II, as well as a lot of questions on X-ray, which was a hot topic at that time. Also, in General Relativity, we find

> *Enunciate Einstein's Principle of Equivalence and explain clearly why it has been called the fundamental hypothesis in generalised theory of relativity.*

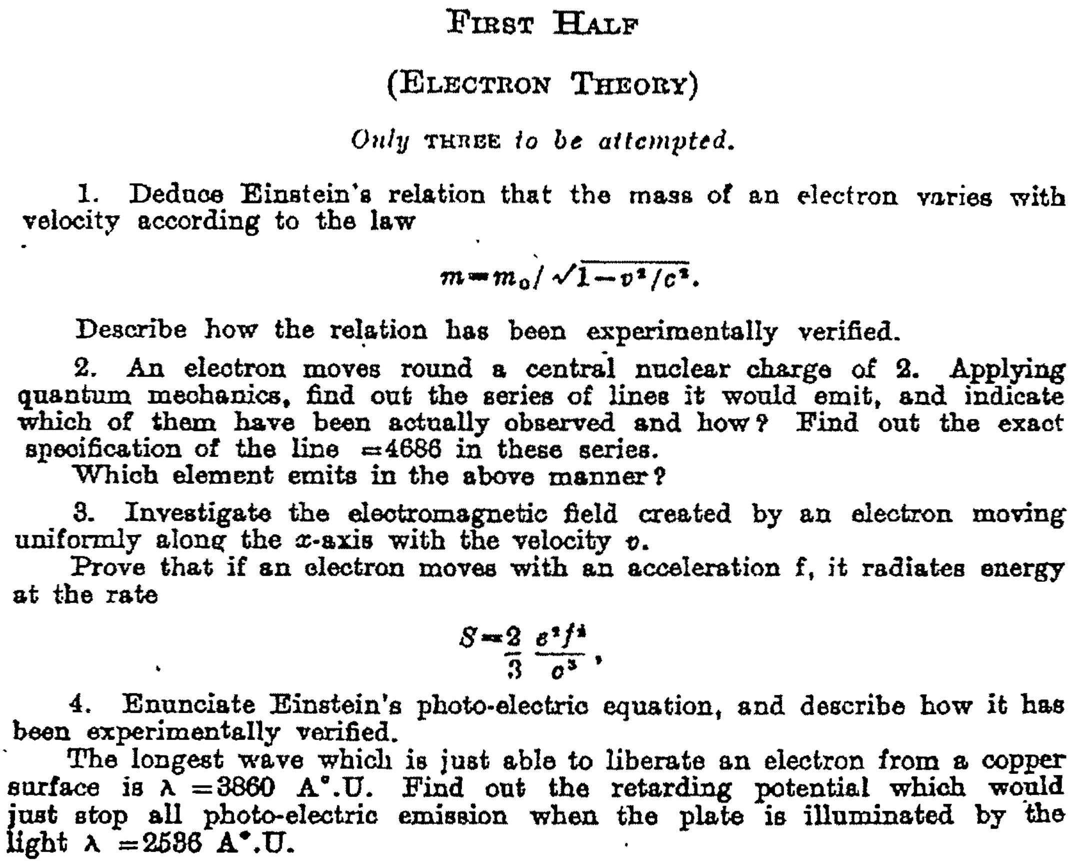
Thus, while the questions are still dominated by 19th century physics, the new ideas and experiments are regularly being taught.

In 1923, the X-ray diffraction (von Laue got the Nobel in 1914) is already in the question paper [27]:

> *Give with theory an account of von Laue's discovery of the diffraction of X-rays.*
>
> Also,
>
> *Give an account of Chadwick's experiment by which the atomic number of certain elements have been determined.*
>
> *Give a short account of inverse Zeeman effect with theoretical explanations.* (This is the Zeeman effect for absorption spectra.)

From 1924, there is a separate section in the question paper for the Light group, called "Quantum Theory". However, the questions were, as it should be, still on old quantum theory and related spectroscopy. The second paper on Electricity and Magnetism was now called simply "Electricity", and had four sections: Electron theory (see Figure 2), which was compulsory, and any one of the three sections of X-rays, Radioactivity, and Relativity. From 1925, Wireless Telegraphy was also another group.

In 1926, we see for the first time a numerical problem in General Relativity (see Fig. 4), where the deviation of light was to be calculated in a Schwarzschild geometry. Apart from that, and a question on Compton scattering, the questions were rather bland. Kinetic Theory of Matter appear as a separate section.



## FIRST HALF

## (ELECTRON THEORY)

*Only* THREE *to be attempted.*

1. Deduce Einstein's relation that the mass of an electron varies with velocity according to the law

$$m = m_0/\sqrt{1-v^2/c^2}.$$

Describe how the relation has been experimentally verified.

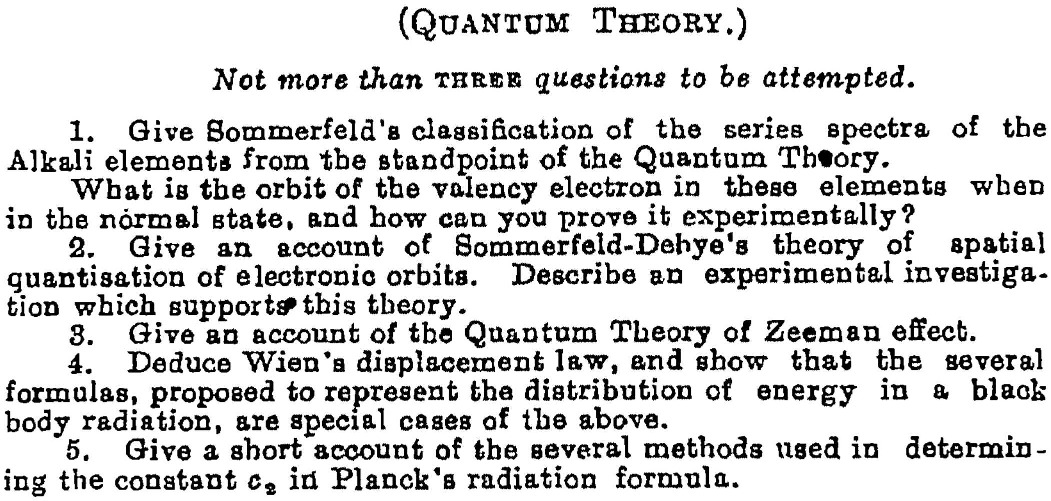
2. An electron moves round a central nuclear charge of 2. Applying quantum mechanics, find out the series of lines it would emit, and indicate which of them have been actually observed and how? Find out the exact specification of the line =4686 in these series.
Which element emits in the above manner?

3. Investigate the electromagnetic field created by an electron moving uniformly along the $x$-axis with the velocity $v$.
Prove that if an electron moves with an acceleration f, it radiates energy at the rate

$$S = \frac{2}{3}\frac{e^2f^2}{c^3},$$

4. Enunciate Einstein's photo-electric equation, and describe how it has been experimentally verified.
The longest wave which is just able to liberate an electron from a copper surface is λ =3860 A°.U. Find out the retarding potential which would just stop all photo-electric emission when the plate is illuminated by the light λ =2536 A°.U.

Fig. 2: Electron Theory, 1924.

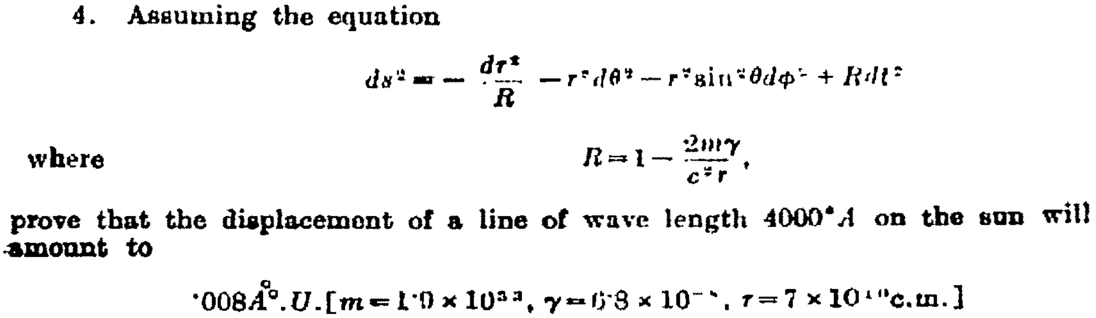


## (QUANTUM THEORY.)

*Not more than* THREE *questions to be attempted.*

1. Give Sommerfeld's classification of the series spectra of the Alkali elements from the standpoint of the Quantum Theory.
What is the orbit of the valency electron in these elements when in the normal state, and how can you prove it experimentally?
2. Give an account of Sommerfeld-Debye's theory of spatial quantisation of electronic orbits. Describe an experimental investigation which supports this theory.
3. Give an account of the Quantum Theory of Zeeman effect.
4. Deduce Wien's displacement law, and show that the several formulas, proposed to represent the distribution of energy in a black body radiation, are special cases of the above.
5. Give a short account of the several methods used in determining the constant $c_2$ in Planck's radiation formula.

Fig. 3: Quantum Theory, 1925.



4. Assuming the equation

$$ds^2 = -\frac{dr^2}{R} - r^2 d\theta^2 - r^2 \sin^2\theta d\phi^2 + R dt^2$$

where

$$R = 1 - \frac{2m\gamma}{c^2 r},$$

prove that the displacement of a line of wave length 4000°A on the sun will amount to

$$\cdot 008\overset{\circ}{A}.U.[m = 1\cdot 0 \times 10^{33},\ \gamma = 6\cdot 8 \times 10^{-8},\ r = 7 \times 10^{10} \text{c.m.}]$$

Fig. 4: Relativity, 1926.

The Richardson equation appeared in 1927 in the Electron Theory section [28]. Also, Applied Physics papers were set from this year, even though the Department was formally established in 1930, when Physics was renamed as "Pure Physics" (this name stayed for a long time).

From 1929, the names of the paper-setters were again printed on each paper. There were still five theoretical papers, four compulsory, and the fifth divided into four groups, of which the students were to answer only one: X-rays (A.C. Saha and D.M. Bose), Wireless (S.K. Mitra and P.C. Mahanti), Spectroscopy (S.N. Bose and S. Datta) and Relativity (M. Saha and P.C. Mahalanobis). S.N. Bose and Saha were away at that time, so obviously the last two papers were taught by Snehamay Datta and P.C. Mahalanobis at Presidency College. These are the predecessors of the advanced papers offered nowadays.

Quantum Mechanics was yet to hit the physics students then, but Relativity was in full swing. In 1930, the paper was set by Mahalanobis and Bose (see Fig. 5). Note, in particular Q. 8 — it shows that the theory of Theodor Kaluza and Oskar Klein, which incorporated electromagnetism as a geometrical effect in a 5-dimensional spacetime, was not unfamiliar to the students, although Klein's paper was published in 1926! It must have been taught from the original papers. At that time, Kaluza-Klein theory was quite hot, as the first attempts of Unified Field Theory by Einstein had also been published.

In 1931, we see the appearance of Saha ionisation formula for the first time, eleven years after its publication:

*Deduce the Saha Ionisation formula and indicate some of its applications.*

K.S. Krishnan appears for the first time as an external paper-setter, and he set a question on Wilson cloud chamber. But more interesting is the electron theory part (Fig. 6): it was set by two antagonists, Raman and Saha, whose relationships must have been quite bitter at that time. S.R. Khastgir acted as an external setter for X-rays. In Spectroscopy, Snehamay Datta and P.N. Ghosh set a question on Raman scattering, but without calling it Raman effect. Bose and Mahalanobis asked the students to write an essay on "Relation of the Relativity Theory and the Quantum Theory" — the introduction of modern Quantum Mechanics for the first time. They also asked them to write an essay on "Recent attempts at developing a Unified Field Theory of Electricity and Gravitation".

## (RELATIVITY)

*Examiners*— { MR. P. C. MAHALANOBIS, M.A.
,, S. N. BOSE, M.SC.

*The questions are of equal value.*

*Answer any* FIVE.

1. Give a short account of Fizeau's experiment to detect the dragging effect on ether by a moving material medium. Explain the phenomena and deduce the numerical magnitude of the co-efficient from the Theory of Relativity.

2. Discuss experimental evidences in favour of the hypotheses of the constancy of light-velocity and its independence from the velocity of the source or the observer.

3. Deduce from the generalised theory of Relativity the perihelion motion of mercury.

4. Briefly review the present state of our knowledge regarding the experimental evidences in favour of the spectral shift towards the infra-red as required by the generalised theory.

5. Write a short history of the Michelson-Morley experiment, and discuss its connection with the special relativity theory.

6. Show that the electromagnetic equations are invariant toward any Lorentzian transformation.

7. Compare the two theories of world structure as developed by Einstein and De-Sitter.

8. Discuss fully the statement—" In a five dimensional universe the world-line of every particle charged or uncharged is a geodesic.

9. Give a short account of Weyl's theory of world-geometry.

Fig. 5: Relativity, 1930.

## (ELECTRON THEORY)

*Examiners*— { SIR C. V. RAMAN, KT., M.A., D.SC., PH.D., F.R.S., N.L.
DR. MEGHNATH SAHA, D.SC., F.R.S.

1. Deduce the equation of thermionic emission
$i$ (saturation current per unit surface) $= AT^2e^{-b}/T$ .
Discuss how it has been shown that the value of $A$ may be deduced from certain universal constants.

2. Deduce the De Broglie expression $\lambda = h/mV$ for the length of the waves associated with an electron moving with a velocity $V$.
Explain how this has been tested experimentally.

3. Sketch the theory of diamagnetism.

4. Give an account of the Bohr-Sommerfeld theory of the hydrogen spectrum.

5. Find an expression for the refractive index of a gas as a function of the frequency of the incident light.

Fig. 6 : Electron Theory, 1931.

The 1932 papers were historic. D.M. Bose, B.B. Ray, Durgadas Banerjee and D.N. Mallik set the first paper where the quantum statistics appeared for the first time:

> *Discuss the assumptions underlying the following statistical methods: (a) classical (b) Bose-Einstein and (c) Fermi-Dirac.*

The fourth paper was set by Raman, S.K. Mitra and Charuchandra Bhattacharyya, where we see the name used for the first time:

> *What is the Raman Effect? Describe the experiments in which it is observed and discuss its theory.*

Also, "state the Pauli Exclusion Principle". In Relativity, Bose and Mahalanobis asked for the "Lemaitre's theory of the expanding universe". In Spectroscopy, Saha and Snehamay Datta set:

> *Account for the spectrum of Hydrogen atom according to Schroedinger's Wave Mechanics.*

It would have been an interesting exercise to compare the standard of these questions with those of leading European and American universities at that time.

## References

[1] Apart from their scales, it is not very clear what the distinction was. Perhaps, the last position was equivalent to a postdoctoral. There were also Assistants to the Professor, not the same as an Assistant Prof.

[2] In the advertisement, the second Chair was wrongly mentioned as for Applied Physics. This was a clerical error; the Senate and Syndicate resolutions later showed the post for Physics. The second Ghose Endowment in 1919 created the Chairs in Applied Physics and Applied Chemistry. While the appointment was made in the Ghose Chair of Applied Physics, the department formally came into existence in 1930.

[3] He was a Professor of Botany, but also acting as the Registrar of the University.

[4] Kramrisch joined in 1924, but the groundwork was done by Asutosh.

[5] The House Allowance was separate.

[6] Syndicate meeting of July 27, 1918. Raman's joining was also recorded in the same item.

[7] It was a long-standing tradition for the teachers of Presidency College to teach in the post-graduate courses of the University. In Physics, we find names like P.C. Mahalanobis, Charuchandra Bhattacharyya, Snehamay Datta and Dwijendrakumar Majumdar in the teachers' list.

[8] This was published in 1918 by IACS.

[9] Mentioned as S.N. Basu in the list of publication. Satyendranath apparently used "Basu" before he went to Dacca.

[10] Raman got interested in the Whispering Gallery problem after a visit to the St. Paul's Cathedral, London.

[11] In those days, his name was spelt as both Meghnad and Meghnath. Raman's report spelt it as Meghnath.

[12] Misspelt as Bibhutibhushan Ray.

[13] This housed the departments of Botany and Zoology and the biological laboratories, also a student hostel.

[14] Made a Palit Assistant Professor in 1919 and a University Lecturer in 1925.

[15] p. 3126 of the Syndicate Proceedings of 1914.

[16] Presided by the ex-officio President, Sir Asutosh, and held on February 28, 1914.

[17] The Upsala (current spelling: Uppsala) and Copenhagen connections were already established by B.B. Ray.

[18] In 1933, he was appointed the Adharchandra Mookerjee Lecturer in Science, and talked on "The Ultimate Constituents of Matter".

[19] Banerjee later came back as a Lecturer.

[20] At that time, he was getting Rs. 125 per month. In his place, Raman employed a laboratory assistant at Rs. 75 and an electrician-cum-mechanic at Rs. 50.

[21] Raman recommended a scholarship of Rs. 100 per month for him but only Rs. 75 was granted, as was the usual norm.

[22] Supported by the Khaira Trust since 1935. Such changes took place because of the rejigs of the Professorial chairs.

[23] Next year we find Sudhindrachandra Roy as a recipient of the Khaira research fellowship. It is not sure whether this is a typographical error, or they were two different persons.

[24] He got support from the Ghost Trust since 1935.

[25] Counting I.Sc. as the first year and B.Sc. as second to fourth years.

[26] Bose and other teachers also set questions in Mixed Mathematics. Similarly, Saha set questions in Physics. In 1918, he was yet to join the Physics Department.

[27] From 1922 onwards, the individual examiners are not mentioned. However, the teachers who were on lien were also included in the examiners' and paper-setters' panel, like S.N. Bose, or later, M.N. Saha.

[28] Without the reflected part due to wave nature of the electrons.

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# Science under European Auspices in 16-18th Century India

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King Manuel I (r. 1495-1521) in whose reign Portugal reached India and Brazil was, like Prince Henry the 'Navigator', the Grand Master of the Order of Christ. He initiated an ornate and flamboyant architectural style, since named Manuelino or Manueline, which combined Christian iconography with maritime motifs such as twisted ropes and corals. All Manuelino buildings depict the cross of the Order of Christ and/or the basic pre-telescopic astronomical instrument, armillary sphere.[1] The latter was in fact adopted by Manuel as his personal emblem in 1499.[2] Gold and silver coins minted by Alfonso de Albuquerque (1453-1515) on his capture of Goa in 1510 also show these motifs. This was Portugal's way of paying homage to navigational astronomy to which it owed its prestige and wealth. The armillary sphere became a recurring symbol in renaissance art and even now adorns Portugal's national flag.

It is often not realized that the Europeans, represented by the Portuguese, arrived in India before the Mughals. They however remained confined to the coastal areas till the Mughal Empire had run its course. In 1757, the British became the masters of Bengal and Bihar. Moving westwards, they reached Delhi in 1803. South India was acquired in 1799 with the annihilation of Tipu Sultan of Mysore, while western India fell to the British in 1818 with the final defeat of the Mahrattas.

When the English East India Company was established in 1600, the telescope had not yet been invented. It is no more than a coincidence that the invention came about in the Netherlands the same year[3] (1608) the first English ship reached India. But this does bring home the important point that modern science grew hand in hand with European oceanic voyages, maritime trade, colonial expansion and domination over nature and fellow human beings. It should however be appreciated that significant progress was made in natural history studies in the pre-Galilean century.

Researches in mathematical sciences and instrumentation to make navigation safe were an all-Europe exercise in which distant lands or their people played no role. In everything else distant lands had a direct or indirect hand. Europe was nature's step-child, with limited natural resources and restricted biodiversity. Vast latitude-driven, ecology-related knowledge resided in distant lands. Europe wished to benefit from this knowledge base, and at the same time produce in its laboratories what nature had given elsewhere. The introduction of gorgeously printed cotton cloth from the East into the 17th century Europe had very profound social and technological implications. Indian textiles became popular with the poorer sections as well as higher classes and served as social equalizers. As Daniel Defoe, who wrote satire during 1691-1727, put it, it now became difficult for the better folk 'to know their wives from their chambermaids'.[4] Developments on the technological fronts were more fundamental; desire to find substitutes for natural Indian dyes led to chemical industry while attempts to replace the Indian weaver with machines produced the industrial revolution.

Oceanic voyages expanded Europe's economy, enlarged its world view, and transformed its state of mind. Huge profits were waiting to be made if ships could sail to distant lands and return home safely. For the first time in the history, prosperity did not depend on the blessings of the God or the good will of the king, but on the initiative of the merchants and skills of artisans and sailors. Maritime imperatives diminished the royal and the feudal holds; enhanced the status of generators of new wealth and knowledge. The French physician Julien La Mettrie would famously declare in 1747 in *The Man A Machine*: "We are no more committing a crime when we obey our primitive instincts than the Nile is committing a crime with its floods, or the sea with its ravages". Europe learnt that knowledge lay not in the past but in the future, not in the archives but out in the open. And knowledge meant survival and wealth. Had Europe's economy remained self-contained, it would probably have had no particular reason to develop modern science.

## Scientific Navigation

The convenience of familiar landmarks disappears when one is in the midst of oceans. To know one's position, the sailor must take the help of the sky and carry out detailed calculations. Professors at Gresham College, set up in 1596 with the new money at the country's commercial hub, London, rather than Cambridge or Oxford, applied their mind to practical problems. In 1615-16, Henry Briggs (1561-1636) introduced logarithm to the base 10 and laboriously prepared tables to simplify mathematical calculations on board. In 1624, his colleague Edmund Gunter devised Gunter scale, the precursor of slide rule. Keeping in mind the requirements of the end user, he wrote his works in English rather than Latin. Similarly, while Newton published his *Principia* (1687) in Latin, his *Opticks* (1704) was in English.

The Royal Society was established in 1660 with its proclaimed emphasis on 'Experimental Philosophy' as distinct from 'the prattling of our book-philosophers'. Astronomical observatories were set up in Paris (1667) and Greenwich (1675) to address the problem of longitude determination in high seas. The Astronomer Royal at Greenwich supplemented his meager salary by giving tuition to young men seeking employment with the East India Company. It paid to join the Company, and it paid to know astronomy.[5] The seriousness of the problem of longitude determination at sea can be gauged from the fact that the British parliament through an act announced a reward of the then huge amount of £20000 to anybody who solved the problem, and set up a Board of Longitude, in 1714, to monitor developments.

In 1730 a poor glazier in far-off Philadelphia, Thomas Godfrey (1704-1749), invented what evolved into a sextant for accurately measuring angles in the sky. It was used in voyages to

Jamaica and Newfoundland.[6] The next year, in May 1731, John Hadley (1682-1744) in England made the same invention (independently, it was claimed). America at the time did not need a sea-faring instrument; accordingly Godfrey's invention remained a dead-end. In contrast, Hadley's invention, independent or not, was immediately adopted by European nations. The longitude problem was finally solved by a carpenter's son turned watch-maker, John Harrison (1693-1776), who began his work in 1730, producing his first sea clock in 1736 and went on to perfect it into a six-inch diameter pocket watch in 1759.

### Scurvy

There was far greater loss of life due to scurvy (now known to be caused by Vitamin C deficiency), on long voyages than due to enemy action or ship-wreck. Even though, the captains and surgeons of commercial ships knew from first-hand experience that lemon juice was efficacious against scurvy, the Admiralty, guided by the learned medical establishment which considered fruits and vegetables to be 'much too primitive and unscientific to be considered as a medicine',[7] went on prescribing such useless cures as elixir of vitriol (aromatic sulphuric acid). It was only in 1795 that the British Navy made lime a compulsory part of diet on sea (earning the epithet limey for British sailors and the British in general). Thus, by the end of the 18th century, thanks to Hadley's sextant, Harrison's chronometer and prevention of scurvy, the mortality rate during the long voyages came down drastically, making large scale colonial expansion possible.

The first disciplines to receive attention from the Europeans were medical botany and geography in that order. Institutionalization of science took place under the British auspices. It began with surveying and natural history and went on to include technologies such as steam, telegraph, railway and radio. Thus, ironically, when we celebrate anniversaries of scientific institutions like the Survey of India, Geological Survey, telegraph or railways, we are also unwittingly celebrating the step-wise entrenchment of the British colonial power in India.

Early scientific initiatives took place in Calcutta and Madras. Major James Rennell (1742-1830) was appointed Surveyor General for Bengal in 1767, two years after the Diwani (revenue collecting rights) of the Mughal province of Bengal was transferred to the East India Company. The Survey of India takes 1767 as the year of its beginning. Asiatic Society Calcutta, established in 1784, provided a powerful intellectual forum not only for Indology but more modern studies also. Dr Johann Gerhard Koenig (1728-1785) was appointed Naturalist by the Madras Presidency in 1778. The post however was abolished 50 years later, in 1828.

Astronomical Observatory Madras was established in 1787 to facilitate coastal survey and provide navigational assistance to ships. Immediately after enlargement of Madras Presidency with the annexation of the kingdom of Mysore, Trigonometrical Survey of peninsular India was initiated in 1800, which was extended to cover the whole country, under the title Great Trigonometrical Survey of India, with effect from beginning of 1818. In 1787 itself, Botanical Garden Calcutta was set up, followed by the revival of Saharanpur Garden in 1817. Coal became important with the introduction of steam machinery. Accordingly, David Hiram Williams

(c. 1812-1848) was appointed 'Geological Surveyor in the Service of the East India Company' in February 1846 to look for coal. For some peculiar reason, the Geological Survey of India takes its year of founding to be 1851 when Williams' successor took charge. My concern here will be with developments up to the end of the 18th century.

## Geography

In the early years, European merchants had no particular reason to venture into the interior. In the early 18th century, when the French and the British started playing an active role in the struggles involving local contenders for political power, it became important to prepare accurate maps and obtain information on routes, rivers, canals, bridges, and hills etc. The first trained modern geographers in India were the Jesuits who had the training, time and the opportunity to criss-cross the country without arousing suspicion. Thanks to the Jesuit connection, first modern maps of India came from the French even though they turned out to be more useful to the British.

The first modern geographers in India were the Jesuits who had the training, time and the opportunity to travel without arousing suspicion or inviting hostility. The French Jesuit, Fr Jean-Venant Bouchet (1653-1732), came to India on expulsion from Siam (Thailand) in 1689. He set up the Carnatic Mission in Pondicherry in 1703, covered the Coromandel coast on foot, and made astronomical and other observations. He prepared a small map of peninsular India which he sent to Paris. Obviously there was some sort of coordination between the Jesuit data collectors on the one hand and the French commercial and political interests on the other, because the Jesuits next sent over several manuscript charts on a larger scale, and other materials which were used by the famous French cartographer Jean-Baptiste Bourguignon D'Anville (1697-1782). He published his map of the southern peninsula in 1737 and followed it by his famous *Carte de l'Inde* in 1752. Proceeding systematically and thoroughly, he consulted old sources like Ulugh Beg and Ain-e-Akbari to get or compare data. In addition, he supplemented his map with a valuable memoir which discussed in detail the sources of data.

Bouchet' colleague, Fr Jean Richaud, discovered in 1689 that the bright southern star Alpha Centauri was in fact a double star. This was the second binary ever discovered. Earlier in 1685 another Jesuit, Fr Fontenay, had discovered from the Cape of Good Hope the first binary Alpha Crucis. Richaud's was the first recorded astronomical discovery from India. The 1680s thus marked a significant step in the European observation of the southern skies.

The significance of D'Anville's efforts can be gauged from the fact that his Memoir was translated, annotated and published with a reprint of his map in London in 1754 and 1759. D' Anville, in turn, became the role model for Rennell. By 1760, the British East India Company had practically the whole of Lower Bengal, comprising the 24-Parganas, Chittagong, Burdwan, and Midnapore under its control. In 1761, Hugh Cameron (d. 1764) was appointed 'Surveyor of the New Lands'. This was the first regular appointment of surveyor anywhere in India.[8] On his death, the appointment was offered to Rennell. In 1767, Rennell was made the Surveyor General of Bengal. He remained in office till 1777, after which he worked at the East India House in London, where he remained influential till the end. In London he regularly prepared maps which were sent out to Bengal in Company ships.[9] His *Bengal Atlas* appeared in 1779-1781. His magnum opus however was the *Map of Hindustan* accompanied by a valuable memoir. The two first appeared together in 1782, but subsequently underwent revisions separately till 1793, incorporating new and improved data. The ascendancy of the British in India coincided with the decline of the Society of Jesus. North India-based Jesuits now became geographical mercenaries for the British.

Fr Claude Stanislaus Boudier (1686-1757), based at the French enclave of Chandernagore near Calcutta, was invited from Sawai Raja Jai Singh of Jaipur for astronomical consultations. The mission was a failure from Jai Singh's point of view, but extremely useful for the British. During his journey both ways in 1734-1735, Boudier fixed the longitude and latitude of many important places, and kept a survey of his route between Agra and Allahabad. Two missionaries from the Agra Mission in its dying days, Fr Joseph Tiffenthaler (1710-1785) and Fr Francis Xavier Wendel (d. 1803), transferred their services to the British, and served the cause of colonial geography well, with the latter even acting as a spy for the British. Tiffenthaler, in addition, performed an extremely valuable service to the British by passing on a 200-year old Jesuit geographical manuscript to them. Fr Anthony Monserrate (1536-1600) was one of the founder members of the Agra mission, set up in 1580. When in 1583 Akbar marched to Kabul against his half-brother Mirza Muhammad Hakim, he took Monserrate along for continuing the education of his second son Murad (1570-1599). Akbar encouraged Monserrate to take observations en route which he did as far as Jalalabad. Akbar however does not seem to have shown any interest in the data collected by Monserrate who kept it with himself when he returned from the journey.

It is reasonably certain that a copy of Monserrate's manuscript was kept at the Jesuit College at Agra from where it was taken by Tiffenthaler who passed it on to Wilford in 1784 a year before his own death. The manuscript went into the valuable *Map of the Countries West of Delhi as far as Cabul and Multan*, which Francis Wilford brought out in 1804. Typically, for additional information, Wilford employed 'A properly instructed native', Mirza Mogul Beg, who carried out extended field work between 1786 and 1796. Hiring of local informers to bring information on roads, rivers, bridges, terrain, etc., was an essential part of colonial geography.

By this time, scientifically trained surveyors had arrived in India from Britain, but their impact was limited. Colonel Thomas Dean Pearse (1741/2-1789) who arrived in 1768 took up the task of training young officials in scientific surveying; Robert Hyde Colebrooke (1762-1808) who served as Surveyor-General of Bengal from 1794 till 1808, was his protege.[10] A brilliant mathematician, Reuben Burrow (1747-1792), who had earlier worked as assistant to the Astronomer Royal, arrived in 1783. History remembers Burrow as the 'discoverer' of ancient Indian algebra. Several notes on astronomy in Francis Gladwin's Ayeen Akbery [Ain-e-Akbari] also appear to have been contributed by him.[11] Colonial service had an interesting social dimension. Pearse came from a respectable but impoverished family. Colonial service for him was a means of restoring the family's fortune. In contrast, the service bestowed respectability on Burrow. In England, he was considered low-bred; in Calcutta he could count Sir William Jones as a friend.

Over the years there was an increase in interest in astronomy as a geographical and navigational aid. Surveying instruments were purchased from England or from the captains and crew of the European ships. When an officer died, his surveying instruments would be in great demand. In the early days, it was not the policy of the Company to supply instruments to its officers. But a small stock of sextants, quadrants, theodolites, clocks, telescopes, etc., was built up by purchases from England or within the country.

The twin events of the transits of the planet Venus across the disc of the sun that were predicted to take place in 1761 and 1769 caused great excitement worldwide, largely because the observations were seen as an extension of the ongoing geo-political rivalry between France and England. Observations from India did not benefit science in any manner but nevertheless produced significant results. They enhanced awareness about astronomy and brought astronomical instruments into India at government expense, which were subsequently used in practical astronomy. The Madras Government had earlier presented a telescope to Nawab Mohammad Allah Cawn [Muhammad Ali Khan], the Nawab of Arcot (the legal owner of Madras lands). It was now borrowed back for the occasion.[12] Astronomical expeditions and instruments were seen as symbols of a superior, science-driven culture. The latter were presented as official gifts to native rulers as show-off even when the latter had no use for them. A land quadrant sent out from England for use by Rev. William Hirst for the 1761 transit was used 24 years later by Pearse for the important route survey from Madras to Calcutta.

The French astronomer Guillaume Joseph Hyacinthe Jean-Baptiste le Gentil (1725-1792) holds the record for the longest scientific expedition in modern times, which unfortunately was a failure. He could not enter Ponicherry in 1761, because it had been (temporarily) captured by the British. He decided to stay in the region for the 1769 event and utilize the period 'to make all observations I could on geography, natural history, physics, astronomy, navigation, winds and tides'. As it turned out, the transit could not be observed because of cloudy skies. Gentil arrived in Pondicherry in March 1768 and stayed here for two years, before and after the transit. He already knew about the ancient Indian mathematical, or Siddhantic astronomy, and took the opportunity to learn the ancient method of calculation of lunar and solar eclipses. The exactness of the method impressed Gentil: 'the error in several which I have calculated amounts to no more than 25 minutes of time' (Hogg 1951, p. 129).

Gentil reached France back in October 1771 after an absence of 11 years. He brought with him astronomical tables from Trivalore, with 3102 BCE as the epoch, and gave an account of them to the French Academy in 1772. Gentil's initiative spurred the British in India, who were in a better position now to interact with the learned pundits, to take up studies in Siddhantic astronomy. Ancient Indian astronomy was separated from astrology through these exercises.

## Madras Observatory

Burrow's 1789 proposal for an astronomical observatory at Calcutta was brusquely turned down by the Court of Directors[13], so that individual astronomical efforts at Calcutta did not have any cumulative effect. In contrast Madras turned out to be more congenial for matters cosmic, thanks to the practical requirements there. As the sea traffic between England and India increased, the drawbacks of the Coromandel coast became abundantly clear. The Bay of Bengal is affected by the monsoons for seven months in the year. Company ships that took barely six days between Calcutta and Madras in the winter months December-April, could require 4-6 weeks at other times. The coast itself is rocky and full of shoals. Madras was not a natural harbour like Bombay was, and did not provide safe landing to Indiamen which were often wrecked. A survey of the coast was thus literally a matter of life and death. Eventually in 1785 a trained surveyor-astronomer Michael Topping (1747-1796) was sent out from England, passage paid and equipped with surveying instruments.

In 1787, an influential Company official, William Petrie, set up a private observatory at his residence at Egmore in Madras and made it available to Topping for his work. Madras Observatory was taken over by the government in 1790, making it the first ever 'state observatory' outside the western world. The observatory was provided with a campus and a building in 1792 in Nungambakkam. In older references, including the Imperial Gazetteer, this date has erroneously been taken to be the date of the founding of the observatory.

Although the Company had grandiosely declared that the purpose of the Observatory was to 'promote the knowledge of astronomy, geography, and navigation in India', it was clear that the main aim was to promote the Company's profitability. Science was only a part of the duties of the Company's officers. The value of various services can be gauged by the price placed on them. Topping's monthly salary as the 'Company's Astronomer and Geographical Marine Surveyor' was 192 pagodas. He got double this amount (400 pagodas) as the 'Superintendent of Tank Repairs and Water Courses'. An additional 100 pagodas came from the superintendence of the Surveying School where half-caste boys were trained.

In the early years, the Observatory was no more than a surveying outfit. This role ended with the 1830 reorganization of the GTS, but navigational need was still outstanding. Increased sea-trade activities of the British required familiarity with the southern skies. In 1844 after 14 years labour, Thomas Glanville Taylor (1804-1848), a former assistant at Greenwich, produced the celebrated Madras catalogue giving positions of about 11,000 southern stars. It was hailed by the Astronomer Royal as 'the greatest catalogue of modern times' and revised in 1893 with funds from the India Office and the Royal Society.[16] Significantly, his citation for the 1842 election as FRS does not mention the Catalogue but refers to his five volumes of astronomical observations at Madras. The citation makes it a point to draw attention to his work that was useful to the ships, namely, series of observations of the magnetic dip and intensity at every twenty miles from Ongol to Cape Comorin.

With the establishment of an observatory in Cape of Good Hope in 1820 and in Sydney in 1858, Madras Observatory became almost redundant from the colonial point of view. India's astronomical fortunes revived with the advent of the new field of solar physics. India was ideal for extensive photography of the sun, which was not possible in cloudy Britain. Also, it was then believed that a study of the Sun will help predict the failure of the monsoons. In 1878 solar photography was started at Survey of India, Dehra Dun, and photographs were sent to England for analysis. A solar observatory was established by the Imperial Government at Kodaikanal in 1899 which still exists as part of Indian Institute of Astrophysics Bangalore[16]. Kodaikanal occupies a prominent place in the world history of solar physics by virtue of the discovery of Evershed Effect, made by John Evershed in 1909. Kodaikanal Observatory is useful to modern researchers because it has the longest uninterrupted time series of solar images taken with the same instrument.

The 1799 defeat of Tipu of Mysore was an event of great administrative and scientific significance. So far the Company had been confined in the peripheral areas in South India, but now it became successor to a well-run state. Its territories now extended from the east coast to the west. From a scientific point of view this was an exciting development because the new lands presented different flora and geology. Post-Tipu, the first task for the Company was the compilation of maps from whatever 'meagre and unsatisfactory material' was already extant. Next, the Governor General ordered a thorough and systematic Mysore survey, the details of which were soon worked out. It was to comprise two components. The mathematical survey would fix the external boundaries and also lay down the 'Country in detail' through primary triangulation. Numerous peaks and hills, 'many of them remarkable for buildings on them' rendered the territory particularly favourable for the exercise. The physical survey would deal with botany, mineralogy, medicine; diseases, weather, rains, soil, agricultural produce, animals, revenue, population, etc. Colin Mackenzie was the over-all in charge of the survey. Within the survey, Francis Buchanan was appointed to investigate 'the state of agriculture, arts, and commerce, in the dominions lately acquired from Tippoo Sultan'. The departments of botany, mineralogy and natural history were entrusted to Benjamin Heyne. Geodetic survey was a new initiative which we shall now briefly notice.

## Trigonometrical Survey

The Trigonometrical survey was started by Major William Lambton (1753/6-1823) who modelled it on the lines of the recently started survey in England. Lambton served in Canada from 1783 till 1796, where he learnt mathematics and carried out surveying and settlement work. His commanding officer in India was Arthur Wellesley (1760-1852), the future Duke of Wellington, whose brother, Richard Wellesley (1760-1842), was the Governor General. This connection helped Lambton win whole hearted support from within India for his proposal. Opposition in England was overcome through another connection.

London-based Rennell, old-fashioned but still influential, when consulted by the Court of

Directors expressed a negative opinion. He however was soon brought around. The Madras Governor Lord Edward Clive (1754-1839) asked for help from the Astronomer Royal Maskelyne who was his mother's brother. Yielding to his persuasion, Rennell informed the Court that he had been misinformed and that he fully supported the proposal.[14] This shows how important networking could be in deciding important issues. The British geodetic survey was a military engineering operation, in which the Astronomer Royal was not involved. The survey in India would also remain a strictly military affair.

Curiously, the requisite instruments reached India from England via China. Many instruments similar to the one made for survey in England were purchased by the Company for presentation to the Chinese Emperor. They however ended as the personal property of Dr Dinwiddie in Calcutta from whom they were officially purchased for Lambton's use. In October 1800, Lambton measured a baseline near Bangalore. This was more in the nature of a dry run, because the real work on Trigonometrical Survey of India began on 10 April 1802 with the measurement of a new baseline in Madras.

A fellow officer of Lambton's in the 33rd Regiment was a French nobleman with the anglicized name, John Warren (1769-1830). As part of the post-Tipu Mysore survey, he became in 1801 the first European to notice the presence of gold in workable quantities at Kolar near Bangalore. Warren worked as assistant to Lambton from 1802 till 1805, and as acting director of Madras Observatory from 1805 till 1811. His most important contribution was the determination of the longitude of Madras Observatory, which continued to be used in official maps till as late as 1905. In 1816, on the death of his elder brother, Warren became the 24th Comte de Warrene. Colonial service was a great European social equaliser. In spite of the sharp contrast in their social backgrounds, Lambton and Warren became very good friends and remained so for 20 years.[15]

On his own initiative, Warren took up the study of the traditional methods of time keeping in South India, and wrote a treatise called Kala Sankalita. Not only his efforts won appreciation from the administration, they also endeared him to the Brahmins who offered to meet the expenses of his daughter's wedding. He got the lunar eclipse of 1801 calculated from a local astronomer and compared the computed timings with the observed ones to show that the former were remarkably accurate for their time. Interest in ancient Indian mathematics and astronomy by mathematically trained Europeans introduced the subject not only to the West but Indians also.

### Natural History

European interest in Indian materia medica in course of time blossomed into scientific botany and, more generally, natural history. In the first phase, during 16-17th centuries, Indian traditional knowledge on plants was conveyed to Europe for incorporation into the mainstream. In the next phase, which is not so well known, Europe-directed studies were carried out by Indian-assisted European missionaries. Finally, pure as well as commercial natural history was supported by institutions set up under British auspices.

The first books on the Materia Medicas of the Americas and India were published in Portuguese and Spanish for the benefit of merchants, physicians, apothecaries and lay persons. For the same reasons, they were translated into other European vernaculars. With a small time lag, these works were rendered into Latin as well, the language of the learned. The vernacular and the learned streams were not antagonistic, but mutually supportive. A work in one language soon became available in the others, very often not as mere translation but as a critically revised and enlarged edition. There was thus a certain collectivity in the European efforts. It is notable that the European sharing of medical knowledge proceeded independently of political and religious strifes. This feature of Europe's sharing scientific knowledge even while fighting over technology, territory or commerce would be seen later in other fields also.

There was a basic difference in how Europe obtained its information from the East Indies and the West Indies. Europe had respect for the high cultural levels of India and therefore no qualms about benefiting from it. In contrast, Europeans were loath to learn from the Aztec people (now preferably called the Nahua). The information from India was accordingly received on site and in an interactive manner. But, the early knowledge about American drugs and remedies emanated from Europe itself, based on accounts received. The American Materia Medica was prepared by Nicolas Bautista Monardes (c. 1493-1588), during 1536-1574, who himself never visited the Americas. In contrast, the (western) Indian Materia Medica came to Europe from (Portuguese) India itself.

The Portuguese physician Garcia d'Orta (1501/2–1568) came to India in 1534 and remained here till death. In 1563, he wrote a book with the translated title *Colloquies on the Simples, Drugs and Materia Medica of India.*[16] It introduced Europe to Western Indian plants and drugs and to details of tropical diseases, such as Asian cholera. A notable feature of the book, not quite appreciated in Europe, was his severe condemnation of academic physicians who blindly followed Dioscorides and Galen.

The well-known translator and synthesizer of his time, the Flemish doctor Charles de l'Ecluse, or Carolus Clusius (1526-1609) abridged and rearranged the text and added valuable notes.[17] His Latin version was published in 1567, which date marks the introduction of non-Western medical botany into the European academic mainstream (because Monardes' translation appeared a little later, in 1574). Clusius' translation achieved great popularity in European countries, and 'is the form in which da Orta's original work was chiefly disseminated for the next two centuries'.[18]

The next major development came a 100 years later, with focus on South India. Hendrik Adriaan van Rheede tot Drakenstein (1636–1691) who was appointed commander of the Dutch Malabar in 1669, was not a botanist, but a botany enthusiast. He brought out a 114-page *Hortus Indicus Malabaricus* in 1678, with editorial and other help, from Amsterdam. It was followed by his magnum opus, the 12-volume *Hortus Malabaricus*, which was published during 1686-1693, also from Amsterdam. It described about 780 species of plants, supported by 794 illustrations.

This work won high praise from professional circles in Europe including from Linnaeus who found it very dependable.

Not surprisingly, the trigger for this notable exercise was utilitarian. The Dutch in the East Indies, already well-entrenched, wished to know about medical plants in South India and Ceylon so as to minimize their dependence on The Netherlands for medicines. For his information, van Rheede depended on the members of the Ezhava community of toddy-tappers, who were 'adept both at tree climbing and plant identification'. Some of them worked as Vaidyars, the traditional physicians with an extensive, time-tested knowledge of the medicinal value of plants. Van Rheede's chief helper was named Itti Achuden (also spelt Achudem). The German-Dutch botanist Karl Ludwig Blume (1796-1862), who worked in Java from 1817 till 1826, honoured Achuden by naming a genus *Achudemia* after him. (Years later, the Madras-based Scottish botanist Robert Wight (1796-1832), named a genus of Orchid *Govindooia nervosa* in honour of Govindoo who illustrated his specimens. The other illustrator Rungia is similarly immortalized in the name *Rungia pectinata*).

On van Rheede's recommendation, a medical doctor, Paul Hermann (1646-1695), was given an appointment in Ceylon where, from 1670 till 1677, he collected plants and prepared a hortus siccus (dry garden) or herbarium.[19] From 1679 till his death, Hermann held the post of professor of botany at Leiden University. The work of van Rheede, Hermann and others in the East Indies established The Netherlands as a centre for tropical botany.

D'Orta and van Rheede were the vehicle for the transmission of traditional Indian botanical knowledge to Europe. In the next phase, post-Linnaean phase, guidelines came from Europe. For the Europeans, 18th century India was a multi-dimensional phenomenon. The merchant-rulers were keen to identify commodities that could be profitably exported to Europe, cultivate commercial plants, and find substitutes for drugs and simples that were obtained from the Americas. The ever increasing scientific community in Europe was excited about the opportunities that the vast landmass of India offered in natural history studies. On their part, the Christianity enthusiasts in Europe viewed European rule in India as a godsend for propagating the Gospel in the east. These seemingly diverse interests converged at various levels. Christian missionaries were not admitted into British territories till 1813. There were a number of small sovereign enclaves held by European countries. In most cases they were insignificant from the commercial and geo-political point of view but came to play an exceedingly important role in the intellectual history of India.

Like in geography, the missionaries were pioneers in natural history also, except that they were Protestant rather than Catholic in the latter case. They constituted a valuable resource for naturalists in Europe. European interest in their field work brought them scientific recognition as well as the much needed cash. More significantly, they introduced the colonial administrators, especially the medical men, to systematic botany. From the second half of the 18th century onwards, individual European naturalists and institutions wanted not only specimens from India but also bits of tacit knowledge resident in local population. The European India was ready and willing to oblige, but as a collaborator rather than a courier. We shall focus on India-based Europeans who built a scientific reputation for themselves; there were of course others who merely served as suppliers.

## Tranquebar and Madras[20]

The small Danish enclave of Tranquebar in South India is the birth place of modern natural history in India. Contrary to popular perception, it was home to not one but two Protestant Christian missions. The older and the better known is the Danish-Halle or Lutheran mission, often known simply as Tranquebar mission, which was set up in 1706. While the India-bound Lutherans were taught theology in Halle, those who additionally wanted education in science subjects were sent to Copenhagen. It was however the lesser known Moravian mission, in existence from 1760 till 1803, which took the lead in natural history studies.

The first modern botanist in India was Dr Johann Gerhard Koenig (1728-1785) who arrived in 1768. He was born in the duchy of Courland, now in Latvia, and was originally trained as a pharmacist in Riga. During 1757-1758 he studied natural history in Uppsala as a student of Linnaeus with whom he maintained correspondence in later years. He studied medicine in Denmark, and in 1764 became amanuensis to Georg Christian Oeder, curator of the newly launched Flora Danica project. It would seem that Koenig's proximity to Linnaeus did not go well with Oeder, and Koenig was left with no alternative but to move out. He came to India to pursue his vocation as a naturalist. His dissertation, dated 1773, was submitted in absentia to Copenhagen University under Professor Friis Rottboel. Koenig then may well be the first person based in India to obtain a scientific doctorate from a European university.

Two Lutheran missionaries arrived in Tranquebar shortly thereafter and were induced into natural history research by Koenig. They became his collaborators and went on to establish high professional reputation for themselves. Christoph Samuel John (1746-1813) arrived in 1771 and his colleague Johan Peter Rottler (1749-1836) in 1776. Like Koenig they remained in India till end. The most celebrated later pupil of Koenig was Dr. William Roxburgh (1751-1815) who was hailed by his contemporaries as father of modern Indian botany. Two later botanists also had a Tranquebar connection. Johann Gottfried Klein (1766-1821) is the first India-born modern botanist. He was born in Tranquebar where his father served in the Lutheran mission. Junior Klein went to Copenhagen to study medicine and returned in 1791 as the mission doctor (Fenger 1863 pp 297-298). His 30-page dissertation dealing with the treatment of venereal disease in India was submitted to the University of Copenhagen and published in 1795. Dr Benjamin Heyne (1770-1819) was a Dane who arrived in Tranquebar in 1793 as a Moravian and was soon engaged by the Company.

There are three shells in the Linnaeus collection marked Tranquebar; presumably they were sent by Koenig. Linnaeus was very keen to obtain specimens from all over the world to fit them into his classification scheme. Europe on its part wished to learn about his work.

In 1760, Linnaeus' student, Daniel Carl Solander (1736-1782) came from Sweden to England on invitation and eventually became personal assistant to Sir Joseph Banks (1743-1820) who exercised tacit control over the Royal Botanic Garden at Kew in his capacity as the royal adviser. With Solander as an intermediary, Tranquebar and Kew entered into a contract whereby Tranquebar missionaries would supply specimens to Kew on payment. Accordingly, as many as 500 specimens were sent between 1775 and 1778.[21] Being known to Banks turned out to be a great advantage to Koenig in his later career. Koenig had repaid the Company 'a thousand-fold over in matters of investment, by the discovery of drugs and dying materials fit for the European market'. Koenig bequeathed his manuscripts and herbarium to Banks.[22]

The pioneering Moravian and Lutheran missionaries called themselves United Brethren no doubt to highlight the fact that though theology pulled them apart, natural history served as a unifying force. Koenig and his collaborators assiduously collected plants throughout the Indian peninsula and in Ceylon, and felt sufficiently confident to jointly assign them names. In such cases, *nob.*, short for the Latin *nobis* (meaning us), was appended to the given name.[23] The specimens were transmitted to Europe, many of which were published in different works, sometimes under the names given by the donor, sometimes under a new name (Wight and Walker-Arnott 1834 p xi). The fact that India-based European naturalists decided to give names themselves shows their level of confidence and knowledge. What the India-based European botanists lacked by way of access to current scholarship and publications was more than made up by the novelty of the material in their hands.

Koenig left Tranquebar to take up full-time appointment as a scientist, while Rottler made himself useful to the Madras colonial establishment in various ways. John however stayed put as a missionary, and financially straitened. In 1774, Koenig accepted the post of naturalist to the Nawab of Arcot.[24] This was probably the first-ever modern scientific appointment in an Indian kingdom. It appears likely that the Nawab was persuaded by his European friends to employ Koenig. The appointment allowed Koenig frequent excursions to the hills and even a voyage to Ceylon. Payments to Koenig however were irregular and in 1778 Koenig successfully applied to the Madras Government for appointment as the Company's first-ever natural historian. (The designation was interchangeably used with botanist and naturalist.) In 1778, he was sent to Thailand and the Straits of Malacca where he remained till 1780. He brought back economic plants such as cardamom and gamboges for cultivation in India as also information on tin ore and minerals. For himself, he collected information on Thai orchids. He thus provides an example of how pure natural history could be dovetailed into the colonial government's commercial interests.

At the close of 1795, Rottler was hired as a Tamil-English interpreter and naturalist 'at a very moderate expense' by Sir Hugh Cleghorn[25] (1752-1837), the first colonial secretary to Ceylon, who was deputed by the government to make a general tour of the island. Rottler's Ceylonese collection was subsequently incorporated into the general herbarium at King's College London (Foulker 1861 pp 7-8). Indian flora reached Canada also. In 1802, Rottler and Klein presented a collection of 168 plant specimens to Sir Thomas Andrew Lumisden Strange (1756-1841), the first chief justice of Madras Supreme Court 1801-1817, who passed on the Madras collection to King's College, Windsor (How 1878 p 373). In 1803, Rottler in collaboration with the German scientist Carl Ludwig Willdenow (1765-1812) published a 44-page paper from Berlin, noticing about 250 plants.[26] He is thus the first India-based botanist to publish in a European journal. In 1804, Rottler severed his connection with the Danish mission and moved to Madras. In 1830 as part of his missionary duties, Rottler began work on his Tamil-English dictionary which was partly published in his own lifetime in 1834. An interesting feature of the dictionary is that it contained a very extensive list of the vernacular names of south Indian plants, along with their technical names. His herbarium eventually reached Royal Botanic Garden Kew in 1872 .[27]

John, financially the poorest of the pioneering trio, collected 'shells and such like curiosities' which he sold to European collectors for 'some hundred dollars which enabled him to pay off his debts'.[28] At a cerebral level, he became a dependable informant for German naturalists. In 1792, he informed Johann Reinhold Forster (1729-1798) about poisonous snakes and the traditional antidotes. Similarly, John was a valuable source of primary information for Berlin-based Marcus Elieser Bloch (1723-1799) who emerged as the pioneering authority on fishes with his well-illustrated 12-volume *Natural History of Fishes* published during 1785-1799. Bloch wrote that 'his assertion respecting the generation of some fishes, that the eggs are retained in the mouth till the young are hatched, has been confirmed by Mr. John, in his last letters from Tranquebar, who says it is a fact known to the fishermen there'.[29] It is interesting to see Indian fishermen's common knowledge emerging as a European research finding.

A grateful Europe honoured the three by making them member of learned societies, awarding them doctorate, and naming species after them. In 1785 Koenig was succeeded by Dr. Patrick Russell (1726-1805) who was already in India on his own. Russell came to Vizagapatam in 1782 where his younger brother Claud, member of the Madras civil servant since 1752, was posted as the chief administrator. One of Patrick's very first tasks after arrival was calling on Koenig in Tranquebar. In Vizagapatam, Russell did not confine his attention to the vegetable kingdom alone but eagerly collected, figured, and described the fishes and the serpents in the Carnatic plain which stretches along the coast of Coromandel. On appointment, Russell was asked to catalogue the economically useful plants of Madras and publish Koenig's scientific notes. It was however not sufficient that the Company naturalists worked for the government. They must be of help to the scientists back home also. Payment to Russell was made contingent on his writing an annual report for the Royal Society.[30] Far-sightedly, he suggested to the Madras Governor that information on all economically useful Indian plants be collected. 'He proposed that letters should issue from the highest authority, inviting the gentlemen, particularly of the medical department, resident at the different stations, to transmit every information in their power concerning such useful plants, accompanied with specimens of each plant, including the leaf, flower, and fruit, with a view to publication.' Russell's plan, with a list of the plants he had selected to begin with, was approved by the Court of Directors which requested Banks to oversee the project. Russell left in 1789, but the project continued.

Russell's greatest contribution was his initiation of a study of snakes. This was a subject of great importance because visit to tropical lands also meant encounter with snakes. He wished to educate the people on the distinction between poisonous and non-poisonous snakes so that a snake bite did not always cause fear and anxiety, and harmless snakes were not killed out of ignorance. Harmless snakes have teeth in both upper and lower jaw, while the poisonous snakes do not possess upper teeth. It may not be prudent to check the teeth while the snake is still alive. Keeping this in mind, he prepared detailed description of various snakes, towards the end of 1787. His write-up and figures were published by the government and widely distributed. His major publications came out after his return to Britain.

The Company took up the expense of publication of coloured figures of the snakes along with their descriptions by Russell. He published the first volume of his book *An Account of Serpents collected on the Coast of Coromandel* in 1796, while the second volume was published in four parts during 1801-1809. He named Red sand boa *Eryx johnii* in John's honour, while his own name was assigned to the viper species. Different combinations, based on different specimens, were tried: *Coluber russelii* (Russell's snake) in 1797; *Vipera daboia*, the genus named after a Hindi word meaning lurker, in 1803; *Daboia russelii* in 1842; and finally *Vipera russelii* in 1890.[31]

Russell also took note of folk practices and subjected them to scientific scrutiny. He acquired numerous samples of *tabasheer*, found in the hollow stem of the bamboo and said to be 'possessed of extraordinary virtue'. The samples were analysed by James Macie and the results presented to the Royal Society in 1790. Tabasheer turned out to be almost pure silica.[32] While tabasheer was a mere curiosity, the so-called Tanjore pill merited serious consideration, because it was presented as a remedy for the bite of venomous and rabid animals. The pill contained arsenic, and the medical opinion on it remained divided.[33]

After Russell, there came a man of outstanding merit and long service. Edinburgh-educated Roxburgh who probably was an illegitimate son of an influential family in Scotland was able to overcome the disadvantage of birth. He began his career as a surgeon's mate on Company ships and joined Madras medical service as an assistant surgeon in 1776. In 1781, he was appointed surgeon to the garrison at Samulcotta [Samalkot] in what was known as Northern Sircars. Located at the edge of a hilly region, 27 miles from one of the mouths of Godavari river, Samulcotta was the site of an old Mughal garden. Now, Roxburgh established a Company garden and began to develop a collection of living plants which he studied for their economic value. In the task of collecting, sorting and naming his material, Roxburgh received direct help from Koenig. In 1786, he reported the significant discovery that 'the Pepper Plant was a native of the Hills in the Rajamundry Circar'. During 1787, Roxburgh procured 400 slips of the pepper vine from the Rampa hills, and within 12 months raised upwards of 40,000 plants.[34] He cultivated coffee, and worked on a number of topics including various dyes including lac and caducay gall; culture and manufacture of silk; and various grasses. He spent considerable time and energy on the study of *Swietenia febrifuga* as possible, but eventually unsuccessful, substitute for cinchona.[35]

Within the overall ruthlessness of the Company, there was individual thoughtfulness which was listened to. Although Roxburgh could not have pointed to the Company how its policies caused famines in India, he suggested that cocoanut trees be planted on canal banks and street side. He also advocated the cultivation of the sago, date, palmyra, plantain, jack, bread-fruit and opuntia, all of which possess food value. He experimented with teak, which would become a priority in the Calcutta garden. In addition to the Company garden which he supervised, Roxburgh set up a private garden of his own. Interestingly, he made a considerable fortune for himself from private trade in collaboration with Andrew Ross, former mayor of Madras.

On the basis of the botanical work he carried out at Samulcotta and Patrick Russell's recommendation, Roxburgh was appointed Russell's successor as the Madras naturalist. We have already noted Russell's proposal for a systematic publication of Indian flora. Roxburgh immediately began work on the project. In 1793, Roxburgh left Madras to take over as the first full-time salaried superintendent of the Calcutta Botanic Garden, and the project went with him.

Initiative for Calcutta Botanic Garden came from Lieutenant Colonel Robert Kyd (1746-1793) who cultivated a private garden of his own. On 15 April 1786 Kyd suggested to the government that plants of the Sago tree growing in the Malay peninsula be brought and grown all over British possessions. He followed this up with a broader proposal, couching it in a mercantile idiom he knew the Company would understand. He suggested 'establishing a botanical Garden, not for the Purpose of collecting rare plants...but for establishing a stock for the disseminating such articles as...may tend to the Extension of the National Commerce and Riches'. The Court of Directors consulted Banks who supported the proposal and emphasized the need for reciprocal exchange of plants and seeds between Calcutta and West Indies. The Company accepted Kyd's proposal on 31 July 1787, seeing 'a great source of wealth' for itself in the cultivation of cinnamon, which would break the Dutch world monopoly. Accordingly, a botanic garden was established in 300 acres in Sibpur on the banks of Hooghly, with Kyd as its honorary superintendent, and with his private garden merged into it.

Speaking in 1899, Sir George King (1840-1909) who had been the superintendent of the Garden during 1871-1897, rather uncharitably described Kyd as a 'gardener rather than a botanist'. However, under Roxburgh the Calcutta Garden moved beyond horticulture and utilitarianism and emerge as a major research centre.

On the transfer of Roxburgh to Calcutta in 1793, Benjamin Heyne, who had been strongly recommended to Roxburgh by Rev. C.S. John, was appointed superintendent of the Madras Presidency's pepper and cinnamon plantations. Bangalore already had a beautiful garden, known as Lal Bagh. It was placed under Heyne's charge, to be appropriated as a botanical. The Governor General's directions were explicit and materialistic: 'A decided superiority must be given to useful plants over those which are merely recommended by their rarity or their beauty, to collect with care all that is connected with the arts and manufactures of this country, or that promises to be useful in our own: to give due attention to the timber employed in the various provinces of his route, and to collect with particular diligence the valuable plants connected with his own immediate profession [medicine].[36] Heyne's own major interest however lay in geology. He wrote on diamond and copper mines and on garnets as also on iron smelting. For completeness, it may be mentioned that Robert Wight (1796-1872), a botanist of great fame, who was appointed in 1826 was the last one to hold the Madras naturalist's post, which as noted earlier, was abolished in 1828.

## Discussion

Early geography was strictly a colonial exercise. The scientific community at large had no interest in it. However, when geodesy came into being, scientists the world over took note of the progress. Also, when clandestine surveys were carried out beyond the Indian subcontinent, the world powers followed the developments for geo-political reasons. Natural history of distant lands however stood apart in the sense that Europe evinced keen interest in it.

In the reign of Mughal Emperor Muhammad Shah nicknamed Rangila (r. 1719-1748), Nawab Sadruddin Khan Faiz declared with insensitivity that was consistent with the spirit of times that 'A low-born person, *razil*, even if he acquires knowledge or skill, cannot become *sharif* [respectable or noble]'.[37] This mindset would have characterized Europe of an earlier era also.

Natural history had profound social impact on Europe. Just as the Indian kings and feudal lords routinely became patrons of dance, poetry and arts, it became fashionable for European royalty and nobility to become collector of natural curiosities. In 1751, Linnaeus was asked to begin work on full-length description of the natural history collection of his King Adolf Fredrik and Queen Lovisa Ulrike. The Queen had a magnificent and unrivalled collection of Indian butterflies and other insects as well as shells. The task was an education for Linnaeus, because he was obliged to create a system of classification of shells. He became quite free with the King and the Queen to the extent that he was among the privileged few to play blind man's buff with the Queen and the courtiers. On such occasions it was a serious breach of etiquette for anyone to touch the Queen, but Linnaeus when he became the blind man could see a little and deliberately caught her. Linnaeus took no note of her reproof and clapped the Queen on the head, boldly declaring that those who play a game must abide by its rules.[38] This is an instructive anecdote. This highlights the social rise of men of science in Europe. Similarly, years later, in 1827, at the newly founded hill station of Simla, the Indian Governor General Lord Amherst and his wife gladly took along Dr. George Govan (1787-1865), superintendent of the Saharanpur botanic garden, on post-breakfast walks so that they could search for plants.[39]

As already noted, most of natural history research in British India was carried out by medicine men most of whom were from Scotland. They came from poor families. Scientific pursuits in India gave them social and professional status back home.A classic example of this rise is Roxburgh as already discussed.

Support for science was a public relations exercise for the East India Company. Just before its 1833 Charter, the Company liberally issued duplicates of plants to botanists of all nations, who were encouraged to examine and publish them. It also transferred its own herbarium to a learned body. 'Such powerful exertions in behalf of science are the proudest boast of a Company which, maligned as it has been, will still remain one of the most stupendous exhibitions of British power'.[40]

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# Calcutta University and Saha Institute

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The Physics Department of Calcutta University (CU) in its Science College campus at 92 Acharya Prafulla Chandra Road is celebrating its centenary year during 2016. It is a very happy occasion for all of us who owe their academic career to the master's course of the department serving as the launch pad.

I entered the portals of Science College in 1951 when the Institute of Nuclear Physics, in close organic linkage with the Physics department, was just a year old. As M.Sc. students of Physics, we had an unhindered access to the institute's well-laid spacious library—a space where we spent most of our off times with reference books and journals. Some of our classes used to be held in the lecture theatre of the Institute and our M.Sc. experimental laboratory in Nuclear Physics was also located on the first floor of the Institute building. In that laboratory we had our first experience of using simple nuclear detectors and learnt how to build and take care of simple electronic circuitry—an exhilarating change from the dreary student-level experiments we were till then accustomed to.

The Institute had sprung out of the laboratory of the Palit Professor of Physics, CU. Meghnad Saha had left his professor's position in Allahabad University and joined as the Palit Professor in CU in 1938. Following the discovery of nuclear fission by Hahn and Meitner in 1939, he had immediately reckoned its importance as a future source of energy. He was also aware of Enrico Fermi's proposal of using neutrons as a projectile to systematically bombard all available isotopes, from the lightest to the heaviest; and with the heavier ones Fermi was hoping to produce transuranic nuclei unknown and unavailable in nature at that time. As a first step Saha immediately introduced an M.Sc. course in Nuclear Physics and succeeded in finding a private donor after some years to buy a radium-beryllium neutron source. He also knew of the 37" cyclotron designed and erected by the University of California at Berkeley by Lawrence and Livingston in 1931. Very soon he persuaded the Tata Trust to donate some money for constructing in his laboratory a replica of the 37" cyclotron. Lawrence had assured to provide him with the design and other necessary assistance. B.D. Nag Chaudhuri was deputed to Berkeley to acquire first-hand experience. During the intervening years of World War II some components despatched from Berkeley got lost on the high seas when the cargo boat carrying them was sunk. Thereafter Saha took a decision to raise a team of research workers and technicians to build all the necessary components including the high-vacuum components, the main chamber, the Dees, the electromagnets, and all the necessary electronic circuitry. A small shed of about 4000 sq.ft. covered area had already come up in 1942 on the Science College premises for housing the upcoming cyclotron.

A lot of preparation and progress towards setting up an Institute of Nuclear Physics under the auspices of CU took place during the decade of 1940-50. The foundation stone for a building of the future Institute was laid on the Science College campus on April 21, 1948 by Shyama Prasad Mookerjee. The Institute made a formal beginning in 1949 as a part of the Palit Laboratory. With a loan granted by the CU the planned building with a floor area of 30,000 sq. ft. spread over three floors were completed by the end of the same year. The ground floor of it was suitably designed so that the earlier cyclotron laboratory became an integral part of it. The building was inaugurated on January 11, 1950, by the Nobel Laureate nuclear physicist Irene Joliot-Curie. This date is now officially considered to be the foundation date of the Institute.

The proposed constitution of the Institute was approved and adopted by the Senate of CU on May 12, 1951. The Institute was granted an autonomous status with its management in the hands of a Governing Body with the Vice-Chancellor (VC), CU as its ex-officio Chairman. M.N. Saha was appointed its first Director.

During the initial years the activities of the Institute covered the following areas: (1) fabrication of the cyclotron; (2) beta and gamma-ray spectroscopy; (3) nuclear mass spectrometry; (4) building a Cockcroft-Walton generator; (5) nuclear magnetism—NMR, EPR etc; (6) ionospheric studies; (7) electronics to support all experimental projects and (8) biophysics.

With the approval of CU and the Central Government the Institute started a one-year Post-M.Sc. training course in 1953-54 with students selected from all over India on a merit basis. This one year course still continues as an important activity of the Institute. At the end of the course the successful students obtain a certificate awarding them the Associateship diploma of the Institute. As far as practicable the new research fellows for the various research projects of the Institute have, since 1953-54, been selected from the associates.

A plot of land adjacent to the western boundary wall of the Science College was requisitioned by the WB Government in 1954 for a second building of the Institute to accommodate a hostel for the students and research workers. J.C. Ghosh, the VC and ex-officio Chairman of the Governing Body of the Institute applied to the WB Government on September 7, 1954, and got a loan sanctioned for payment to the owner of the plot situated on Kalidas Sinha Lane. The boundary wall of Science College was broken up and suitably rebuilt to integrate the purchased piece of land with the existing campus. The Central Government sanctioned Rs. 1,60,000 in November 1954 for the construction of the building. K.D. Malviya, the concerned Central Minister and Saha's student from his Allahabad days, laid the foundation stone of the new building on January 19, 1956.

Another worthwhile achievement during these years was the establishment of the Sur Readership of CU with an endowment by M.M. Sur, an industrialist and ex-student of the Physics department. It was agreed that the Sur Reader will be granted office and research facilities in the Institute building. This arrangement has continued for many years till about

1983-84 when the then Sur Reader became an active full-time member of the Physics department.

In 1955 the Central Government approved a five-year plan for the Institute to take effect from the next year. A secretarial decision was taken that the central funds will be controlled and disbursed through the Department of Atomic Energy (DAE). M.N. Saha had already voiced his opinion opposing the attempts of DAE to regulate and control nuclear researches in the universities. He had pleaded for a small research reactor for CU but the DAE had overruled his request in the name of secrecy, although at that time small research reactors were commercially available and had been installed even in many colleges in the USA. Of course, Saha was very unhappy about the stricture of DAE supervision on the five-year plan of the Institute and on February 16, 1956, while on his way to his friend J.C. Ghosh in the Planning Commission to discuss the matter, he died on the street of Delhi of a sudden heart attack.

After Saha's death B.D. Nag Chaudhuri was appointed as the Director of the Institute which was renamed Saha Institute of Nuclear Physics (SINP). The 'orphaned' Institute thought it prudent to accept the decision of the Central Government in toto and ensure the security of a regular flow of funds. Meanwhile the hostel building became ready for occupation. Apart from the hostel, a portion of it was used for the growing administrative offices and a few new research projects as well. On the research front, the Cyclotron became operational in 1960 with completely indigenous efforts. The internal proton beam was used as a source of producing isotopes for in-house nuclear spectroscopy and some tracer applications by a small group engaged in medical research. Somewhat later when the external beam became available, some scattering and reaction experiments were also done.

Around this time the Biophysics Division had to go through a change of venue. According to some sources, M.N. Saha had originally planned to nurture the activities of this Division to a viable point and then transfer the entire set-up to a new campus as an independent institute specialising in biosciences, health physics, tracer research, medical applications of radioisotopes etc. N.N. Dasgupta, the Head of the Biophysics Division, succeeded in negotiating with the WB Government for the gift of a plot of land inside the Veterinary College campus in Belgachia. With a grant from the Central Government in 1964, a new building was built with boundary walls to demarcate the gifted land. The Biophysics Division was then completely shifted to this new campus in 1965. The present author is not aware whether the SINP Governing Body, at that time, received and considered any proposal for converting the division to an independent institute. If it did, the proposal must have been rejected. The fact is that the division has always remained an integral part of SINP.

During 1964-65 the DAE planned to set up a Variable Energy Cyclotron (VEC) as a national facility, and Calcutta was finally chosen as the site. In 1969 the WB Government made available the land needed for this purpose in the newly developed Salt Lake area of the city on payment of the officially fixed price by the DAE. At the same time the WB Government generously gifted to SINP an adjacent 7 acre plot of land for setting up its permanent campus comprising laboratories, workshop, offices, etc. On two later occasions in 1971-72 the same Government supplemented the initial gift with further gifts of a total of about 6 acres of contiguous plots. The Institute had plans to build staff quarters and a students' hostel-cum-guest house on this latest acquisition. Preparations for shifting the entire Institute from the CU Science College to the newly acquired land in Salt Lake officially started in 1972.

In the same year the original constitution of the Institute was replaced with a tripartite agreement jointly signed by (1) the CU, (2) the WB Government, and (3) the DAE as the hands of the Central Government. The management of the Institute was vested to a council of which the VC, CU was still the ex-officio Chairman; the other members were to be nominated by the three parties. The concurrence of the three parties to the appointment of the Director of the Institute was made mandatory. The agreement specified a minimum annual grant of Rs. 60,000/- from CU, Rs. 1 lakh from the WB Government, and 20 lakh from the Central Government. However, it was tacitly understood that the entire recurring and non-recurring grants in the five-year plan of the Institute would be examined and approved by the Central Government and once approved, it will come through the DAE subject to rules and regulations concerning proper utilisation. This historical step, in retrospect, can be viewed from two distinct perspectives. First, it definitely paved the way for the extension and proliferation of the research areas of the Institute with assured funds, and about a decade later it smoothly led to the sanction of the salary scales, promotion schemes, pensionary and medical benefits for the SINP employees in perfect alignment with those for the DAE employees. These academic and material benefits cannot certainly be underrated. However, the second and the completely de-emphasized perspective is that after the first onslaught in 1955 that Saha tried to prevent, this tripartite agreement dealt a major blow to his steadfast endeavour of keeping the Institute in a close linkage with the university.

The first landmark in the development of the Salt Lake campus bears the date March 12, 1977, when the foundation stone of the laboratory building was laid by H.N. Sethna, the then Chairman of the Atomic Energy Commission and the Secretary of DAE. With a DAE grant of Rs. 88 lakh on civil work, the first phase of the building with a covered area of 75,380 sq. ft. spread on four floors was ready in March, 1979. After arranging suitable transport and communication between the two campuses, a number of research divisions and the entire administrative office were shifted to the Salt Lake campus in 1983; only the Director's office was retained at both places. The foundation for the second phase of the laboratory building at Salt Lake was laid on October 7, 1986, and it was ready for occupation in 1988; it added another 53,843 sq. ft. of covered area.

Meanwhile the SINP council had taken a decision assuring CU that on completion of the second phase building, the entire Institute will be shifted to Salt Lake and the two buildings on Science College campus will be handed over to CU. Since the hostel building was built with the Central Government funds on land owned by the Institute, it was agreed that the university would pay to SINP an agreed token compensation for that building. CU completed the formalities in 1986. In 1988 when all the research divisions were shifted to Salt Lake, the two buildings were handed over to CU. By the courtesy of the university, the hostel with a few post-M.Sc. students was allowed to temporarily stay in its place pending completion of a hostel building in the Salt Lake campus.

In 1986 a proposal for building staff quarters and a hostel cum guest house met with an objection raised by the Salt Lake authority on the ground that the land gifted by WB Government can only be used for educational purposes and not for residential buildings. The problem was finally solved by the direct intervention of the then WB Education Minister, and the work started behind schedule by a couple of years. Some lower category residential quarters were completed with priority. The higher category ones and the hostel cum guest house were ready in 1994. The students' hostel from the CU campus was then brought to the Salt Lake campus, breaking the last vestige of a nominal bond with the university.

Already in 1992 a major constitutional change had taken place breaking the single real bond that existed after 1972 via the first tripartite agreement. The new tripartite agreement signed in 1992 replaced the VC, CU as the ex-officio Chairman of the SINP Council by the Secretary, DAE. The provision of the nominal official grant from CU and the WB Government was abolished, and the DAE became the sole arbiter and provider of funds. The Institute since then is officially treated as an autonomous institution under the administrative control of the DAE.

In a couple of years the third phase laboratory building, attached to the linear first and second phase buildings forming an L-shape, and an auditorium complex were added to the SINP campus. The biophysics division was then brought to the same campus from Belgachia, ending many years of separation from the parent body. In 1999, R. Chidambaram, the then Secretary of DAE, laid the foundation of a High-current Separator Laboratory on the land behind the L-shaped main laboratory cum administrative building. In the same year a canteen complex had come up in an adjacent space. In the year 2000, the then WB Chief Minister, Mr. Jyoti Basu, unveiled a bust of Irene Joliot-Curie. Very recently the statue has been installed next to the completed High-current Separator building (also called the surface physics building) in the presence of her son, Pierre Joliot, a professor of biology in CNRS (France).

As of today the research activities of the Institute have diversified into many different areas: nuclear physics theory and experiment, high-energy and elementary particle physics, condensed matter physics, low-temperature physics, surface physics, plasma physics, mass spectrometry, nuclear chemistry, crystallography and molecular biology, biophysics, structural genomics, collaboration projects on experimental high-energy physics with CERN, Geneva, collaboration projects with Darmstadt laboratory in Germany, and with KEK accelerator centre in Japan. With a galaxy of reputed faculty members, a praiseworthy record of publications and citation index, the Institute is now well-recognized as an advanced centre of basic research in India.

I am indebted to Atri Mukhopadhyay for providing me with many data with dates included in this article.

Professor Manoj Kumar Pal did his M.Sc. from the Physics Department of CU in 1953 and his Ph.D. in 1958. He is a theoretical nuclear physicist and served as the Director of Saha Institute of Nuclear Physics. He is a Fellow of the Indian Academy of Sciences, and the Indian National Science Academy. Apart from his works on the history of Indian science, he has also authored two well-acclaimed textbooks on Theory of Nuclear Structure and Theory of Relativity.

# Amateur Physicists in Colonial India in the Romantic Era

**Biman Nath**
Raman Research Institute, Bangalore

The era of colonial officers in India dabbling in science before 1857 is often regarded as a curious but insignificant phase in the history of development of science in this country. There are many reasons for this attitude. These scientist-officers worked far from the centres of European science, and their work was often dismissed by their peers in Europe, or at best viewed patronizingly. Consequently their work failed to impress the professional scientists of later years, as well as science historians. Also, the bureaucrats who replaced them in the later half of the 19th century viewed them as either incompetent officers or crazy scientists, or both. There is a tragic sense in the way most of these scientists disappeared after their stint in India and died in obscurity.

This is particularly true in the case of topics such as physics. Officers interested in the flora and fauna of India, or its geological features, could report on their discovery of exotica, and their papers were received with eagerness and enthusiasm by their European peers. However, papers that described physical experiments carried out in India did not have such a privilege. There was no aura of Asian exotica in their experiments, and no one expected anything in their reports that required one's presence in India. Consequently they were mostly dismissed as the works of dabblers in physics. This fate of their papers was not lost on the authors. The anticipation of how their works would be received in Europe made some of them to indulge in hyperboles.

For example, R. Tytler claimed that he had discovered electromagnetism independently, if not before Faraday in England. In another communication, he proposed a theory of rock formation that challenged Newton's theory of gravity for the same. Pratik Chakrabarti has noted: '*Unfortunately there is no evidence that his interesting propositions were followed up by others or even whether they reached the scientific community of Europe at all. Probably not. Such was the fate of most other claims as well. Tytler's career is that of a typical colonial scientist, who worked in an obscure part of India, silently carried on his projects, contributed to journals from time to time, occasionally made interesting discoveries and were emboldened enough to challenge the works of scientists at the Centre, but who died without receiving any form of recognition from that community.*'[1]

There is another aspect that makes these scientists important in the history of science in India. These scientists belonged to the so-called Romantic era, which emerged as a protest against the sentiments of the Enlightenment Era in Europe. Their outlook was based on a more holistic manner than their predecessors, and their attitude towards their Indian assistants was markedly different from their predecessors, in the sense that they were not as dismissive. The reason for this earlier attitude of supremacy and complacence can be detected in the colonial gaze of the rulers. The early colonizers of the 18th century often felt the need to show Indians in poor light, to be '*unscientific, superstitious and resistant to change*' in order to '*legitimize their own rule*'[2]. The officers who came later, in the last couple of decades of the rule of the East India Company, however, saw the advantage of working in tandem with Indian assistants, and were not uncomfortable with promoting them to rather high levels.

Hyperboles aside, a few of these amateur scientists did manage to do world-class science from India. The significance of their work is often skipped even in modern discourses. One such person was Major James Francis Tennant. He came to India in 1849 after graduating from the Addiscombe College, the military seminary of the East India Company, with a distinction in mathematics. In this regard, he was different from the earlier generation of colonial officers with an interest in science. The earlier officer-scientists were mostly doctors, because at that time the only institutions in England where one could get something close to a scientific education were the medical colleges. Tennant's father had been a brigadier-general posted in Calcutta, and quite naturally Tennant chose to come to India after his studies. His mathematical bent of mind found a niche in the Great Trigonometrical Survey, where he was assigned to work.

Tennant was working on the Western section of the Survey when he hit upon something that changed his life. Starting from Sironj in central India, Tennant's team inched westward and reached Karachi in four years, covering a distance of roughly 1500 km. By that time he had established himself as a careful observer, and when he measured the latitude of Karachi, he decided to send his report to the Royal Astronomical Society in 1853, unlike his predecessors who would have written to the Asiatic Society in Calcutta.

Working with surveyor's theodolites, he then became interested in the mechanical aspects of weight distribution of the instrument. One of the common problems of telescopes and theodolites is to balance the weigh of different parts. An unbalanced telescope with moving parts puts strain on it and wears out the gears. The traditional method to overcome this problem is to 'relieve' the weight through spring, but they would have to be sufficiently stiff in order to account for the variable friction. Another method is to use counter-weights. Young Tennant thought this method unsatisfactory: '*[They] add to the weight of the instrument; and where the instrument travels, they must be previously removed, of which perhaps the inconvenience can only be appreciated by those who have had to dismantle and pack up instruments late at night, when wearied with a long day's work.*'[3]

He then came up with something completely new, and suggested that an oil reservoir could act as a 'hydraulic relief' of a theodolite or telescope. He worked on it extensively and wrote a paper that dealt with 'a method of relieving the weight of the moving portion of an alt-azimuth telescope'. Little did he know that this method of balancing the weight of a telescope would one day become a common tool. Especially with the construction of large telescopes in the beginning of the 20th century, where balancing became a critical issue, this idea came to be widely used.

The first successful use came with the construction of the 60-in telescope at Mt. Wilson in the USA in 1908, where the weight of the moving parts were relieved with the help of a mercury float.

Unfortunately, Tennant's paper from India on this idea has been largely forgotten by now. However it was much appreciated at that time. One of his friends in England, A.A. Common, used the idea for the construction of a 5-ft equatorial telescope. Unlike many of the colonial officers whose work was dismissed back home, Tennant was nominated for a fellowship of the Royal Astronomical Society that year and was duly elected.

Tennant was summoned to Delhi at the outbreak of the Sepoy mutiny and he fought during the breaching of Lahore Gate, which finally led to the breakdown of the sepoys' defense. He was then sent to Lucknow to help lift the siege of the Residency there. It so happened that Lucknow was the only place other than Madras to have a modern observatory at that time. The '*Taronwali kothi*', as it was called, had been closed down for various reasons, mostly financial, by Wajid Ali Shah, and had been a festering issue in his relation with the British. Tennant was curious about the instruments in the observatory, and wrote a report for the Royal Astronomical Society, despite the tumultuous events of the mutiny that surrounded him at that time. He wrote: '*I believe I was the only member of the Society present at the capture and occupation of Lucknow, and I think possibly some account of what has been the fate of the observatory and instruments may, though removing almost all hope of the latter ever again being found, be not uninteresting.*'[4]

Tennant later became the Government Astronomer after the mutiny, and then the master of the Royal Mint in Calcutta, before returning to England in late 19th century. He even became the president of the Royal Astronomical Society in 1890.

Another person who had done frontier research in physics around that time in India was not so successful in shaping his career path. William O'Shaughnessy, an Irish, came to India in 1833 as an Assistant Surgeon in the Bengal Medical Service after studying medicine in the University of Edinburgh. He was soon appointed a professor of Chemistry at the Medical College in Calcutta, at a time when the government began to view science and technology as an important initiative. True to the Romantic spirit of the era, O'Shaughnessy began experimenting in different fields of science, including writing papers on the medicinal use of cannabis and hemp. Within a few years he began to experiment with electricity, and by 1839, at the age of thirty, he set up a 13.5 mile long demonstration telegraph system. This was only two years after William Cooke and Charles Wheatstone patented electric telegraph in England, and a year after Samuel Morse built his demonstration system in the United States.

What is more interesting is that O'Shaughnessy tried a variation of his experiment by attempting to complete the circuit with the river water, without any connecting wire. He achieved this feat in the same year 1839, with 1.8 mile of the Hooghly river water to complete the circuit. One point where the wire was dipped into the water was 'the ghat of Bishop's college' and the second point was 'at Sir John Royd's garden'. He noted that *'it made no perceptible difference whether the tide was ebbing or flowing; in several trials even the damp mud conveyed the signal unaltered in force or character.'*[5] In another attempt, he increased the length of the 'water circuit' to 2.5 miles. Interestingly, this was three years before Morse tried out a similar experiment, sending a signal through the waters of the Chesapeake and Potomac Canal in Washington DC in 1842. O'Shaughnessy's experiment was arguably the first time that 'wireless' transmission of electrical signal was ever attempted.

O'Shaughnessy also tried something unique that year. He hauled a wire insulated with split rattan and tarred yarn across the river Hooghly because he realized that it would be difficult to hang the wire above the river. This was also years ahead of anyone else. Seven years later, in 1846, Samuel Colt (famous for the revolver) and George Robinson of New York laid an underwater cable between Manhattan and Brooklyn. Five years later, an underwater cable was laid across the English Channel.

Lord Dalhousie, who became the governor-general in 1847, heard about O'Shaughnessy's experiments and realized its strategic importance. Dalhousie directed him to construct a telegraph line, first between Alipore and Diamond Harbour, and then to extend it to Agra, Bombay and Madras. It is interesting that one of his trusted right-hand man in this ambitious endeavor was an Indian named Sib Chunder Nandy, who was his chief accountant and head signaler. There were occasions when O'Shaughnessy defended and even rewarded his assistant, sometimes to the chagrin of other British officers.

During this remarkable project, O'Shaughnessy had to experiment with various material for insulation, and not depend on what his European peers suggested. At times he used rosin and sand, and when they were not available (for example, when he extended the line to the present day Rajarhat), he tried cloth and tar. Instead of a wire, he used iron rods. Another of his innovation was to use bamboo poles for supporting overhead wires. He argued that bamboo posts would resist storms, and is cheap enough to replace it easily when it decayed beyond use.

A contemporary report from the Scientific American describes O'Shaughnessy's innovations thus: *'...the thickness of the wire allows of their being placed on the post, Without any occasion for the straining and winding apparatus, whereas the tension of wires exposes them to fracture, occasions expense in construction, and much difficulty in repairs; the thick rods also admit of rusting to take place, without danger, to an extent which would be fatal to a wire. On several occasions, one village forge, carried by two coolies, has been found sufficient for welding a mile of rods in a working day. The rods, moreover, are not likely to be injured by crows or monkeys. Swarms of kites and crows perch on the lines through the swamps but they cause no harm; the correspondence flies through their claws without interruption, though on one occasion a flash of lightning struck the wet rod, and killed some scores of them. The importance of this discovery of the superiority of rods over wire will be fully appreciated in a country like India, where the line must often run through a howling wilderness, tenanted by savage beasts, or more savage men.'*[6]

The rest is history, and Dalhousie's idea was proven right during the mutiny when telegraphic communications helped the British forces overcome the sepoys on many fronts. Dalhousie had recommended O'Shaughnessy for knighthood even before these events (in 1856), but O'Shaughnessy's career nosedived afterwards. After he retired to England, his successors in India started calling him 'a mere theorist' and criticized his choice of insulators for the wires, and asked for ceramic insulators that European physicists had suggested. Saroj Ghose, in his discussion of O'Shaughnessy's career, suggested that the fallout between O'Shaughnessy and his successors was mainly because of the difference in temperaments. According to Ghose, O'Shaughnessy's '*scientifically oriented mind and flexible approach induced him to carry on new experiments even when some of them proved failures.*'[7] He was after all a product of the Romantic era. However, his successors were more bureaucrats than passionate engineers, steeped in the ideals of following rulebooks. They had '*more faith in established and well proven practices rather than in uncertain experiments*', and some of them, by virtue of their service in the army, were '*accustomed to a regimentation of thought and action*'.

O'Shaughnessy gradually '*became a non-entity in the very enterprise that he himself had built.*' He had requested to be associated with the development of the Indo-European telegraph line, but the India Office in London ignored all his pleas. His life faded into obscurity barely two decades after his audacious experiments on wireless telegraphy.

The times had changed. The practitioners of science had become more professional, associated with universities and laboratories, and technocrats, rather than passionate amateurs, had come to rule the administrative sections of the government.

The era of amateur officer-scientists in colonial India had come to an end and was quickly forgotten.

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Dr. Biman B. Nath is a Professor of Astrophysics at the Raman Research Institute, Bangalore. Apart from his research, he regularly writes popular articles of science, in English and Bengali. He got the Indira Gandhi award for science popularization from the Indian National Science Academy in 2011. His books include: *The story of helium and the birth of astrophysics* (2012), *Eyes on the sky: The story of telescopes* (2009), *Dawn of the universe* (2005), *Nokkhotrer gan* (2007), *Mohabishwer prothom alo* (2002).

# Sailendra Nath Ghose
# The Man who started the M.Sc. Physics Laboratory

### Excerpts from his autobiography

The Physics Laboratory for the M.Sc. students was built by someone whom very few people now remember, at least as a physicist—Sailendra Nath Ghose. He had an extraordinary career; the son of a teacher in Jessore, he did his intermediate from Ravenshaw College in Cuttack, and then got admitted to the Presidency College in Calcutta in 1911. In 1915, he passed his M.Sc. with a first class (at that time, only Presidency College had a postgraduate course in Physics). Only two students got first class in 1915; the other was Snehamay Datta. During the masters thesis, Ghose became interested in building up the Physics Laboratory with the active help of Sir Asutosh, who almost handpicked him, and the Maharaja of Cossimbazar. He was later selected for the Palit Fellowship to spend three years in America, when his passport was confiscated by the police just before he was about to depart. He had a close connection to the freedom movement and to the revolutionaries of the 1920s (in particular Jatindranath Mukherjee or Bagha Jatin) as a member of the Jugantar Dal. He fled India in 1916 as a stoker in a City Line ship, and came to Mexico with Manabendra Nath Roy and several others. While Roy stayed in Mexico and founded the Communist Party there, Ghose travelled to San Francisco in 1917. He, along with Tarak Nath Das, founded the Friends of Freedom for India, and was also actively involved in the Indo-Irish joint movement for Irish independence.

While in America, he published the story of his life in the Asia magazine (vol. 27, no. 7-9, 1927). This is a fascinating article, and here are some excerpts from it.

**** **** ****

My father's home was at Kurigram, in Jessore, arrd my mother's home at Senhati, in Khulna, the first about eighty-five miles and the second one hundred and ten miles from Calcutta. My birth occurred at the house of my Senhati grandmother, my mother having gone there, as was the custom, for that event. Since I was the first male child born in the family of my maternal grandmother for a long time, she emphasized the Hindu preference for male children by giving me, for her own particular use, the name Amullya [*sic*], "the priceless one." But my actual name, Sailendra, was given me by my cousin, the eldest son [Ramendra] of my father's eldest brother.

**** **** ****

In the interval between securing my bachelor's degree and taking my master's degree, I was obliged to face the fact that my father wished me to marry, Some innocent pretext was devised to secure my presence at Ramendra's house in Krishnagar[1], and, on my arrival, I found that a bride had been chosen and a dowry arranged, by means of which I should be enabled to go to England. But I had become so imbued with revolutionary ideals and so involved in revolutionary activities that I was not just then at all desirous of marrying. Accordingly, I put my family off with the statement that I intended to take a doctorate in science and could not consider marriage until I had completed my education.

The work for the master's degree involved my remaining quite alone at the college through the summer months. I had full access to all the laboratories and the keys to all the rooms, where instruments and materials were kept. On the suggestion of Mr. Harrison[2] I began to examine the properties of copper under conditions of high temperature, but in the course of the year I was led to change to another series of experiments, so that my master's thesis was on "Some Properties of Iron Deposited Electrically in a Magnetic Field." There was plenty of patience required; for at one time I recorded the temperature every hour for fifteen days. A friend helped me in this struggle against sleep.

This work brought me under the favorable notice of the late Sir Asutosh Mookerjee, Vice-Chancellor of the university, who sent me on a tour of the colleges in the neighborhood of Calcutta to see what instruments could be begged or borrowed with which to set up a department of research in physics in the newly created College of Science. I reported to him one day that I had found some good material at a college maintained by the Maharaja of Cossimbazar[3]. "That is good," he commented; "I am going up there next week to unveil a portrait. You had better come with me."

So I accompanied him, and we were the Maharaja's guests for the day. I have a very distinct recollection of the magnificence of the service. A course dinner was served, and I was presented with an immense plate, made of pure silver, on which were one hundred and eight small silver cups, each containing a separate article of food. Good manners required that the guest should partake of part or all of the contents of every one of these cups. We did not use forks or spoons. Fingers were supposed to serve instead. It was not difficult for a strong young man to make a good meal from a dinner of one hundred and eight courses. Meantime, on the Vice-Chancellor's instructions, I got myself shown about while he was delivering his address. Later, when the Maharaja was personally conducting him through the building and they came to where I was, he said to me, "Well, have you found anything here that you must have?" I told him there were many things, some of which were not being used.

By this time the Maharaja was interested, and the Vice-Chancellor told him of our plans. "Just let me know what you want," was his comment, "and if we can spare it you may consider it yours."

The Vice-Chancellor continued to take an interest in my welfare, But just as he was on the point of doing me a very great favor, something entirely changed the current of my existence. What happened then constitutes in fact, a whole chapter of my life experience.

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All through the winter of 1915 and the spring and summer of 1916 I was at work on a project for which Sir Tarak Nath Palit, a wealthy Hindu, was sponsor. Sir Tarak Nath had his own idea about how he could best serve his country. In setting aside three million rupees with which to found a graduate college of science in Calcutta, he parted with practically everything he owned. The gift was made on condition that none but Indians should be included in the work of the college, whether as instructors or as students, and that no foreigner should become in any way a beneficiary of the trust. Through the kindness of the late Sir Asutosh Mookerjee, Vice-Chancellor of the University of Calcutta, I was given a part in the work of getting the college ready to receive students and was commissioned to recruit a small group of recent science graduates. The business was all-engrossing. I should have had no time available just then for political activity, even had there been any demand upon me for it, as in fact there was not.

Toward the end of the term, in May, 1916, I was informed by Sir Asutosh Mookerjee that I had been nominated for the fellowship in physics given by Sir Tarak Nath Palit. They had decided that it would be wise to send some one to America to study for three years. I had been selected, and I was to go to Harvard University. A promise not to marry while abroad was required of me, but otherwise there were no restrictions. The money provided would be ample for my needs. So my passport was applied for, and, after a month spent by the authorities in investigation, it was received. With my passage reserved, I had gone to Krishnagar and said good-by to my family, and on a Wednesday in July, 1916, I was to leave Calcutta to take the ship on Saturday from Bombay. But on Monday a police official came, took away the passport and informed me that I was not permitted to leave India. Greatly puzzled, I went at once to see Sir Asutosh Mookerjee at his home.

He was as much mystified as I was. "Do you know of any reason for this action, anything by which it can be explained?" he asked. "No," I answered truthfully; for I had just then no inkling of precisely what revolutionary activities of mine could have been discovered. "Very well, leave it with me till the morning, and I will see what I can learn."

After I went away, Sir Asutosh called the Governor of Bengal, Lord Ronaldshay, by telephone, but there was nothing to be learned in that quarter. The Viceroy, Lord Chelmsford, said that he had heard nothing about the affair and that it must concern the India Office, in London. I wondered whether, if I offered to go to England instead of America, I might be allowed to do so. Sir Asutosh undertook to find out, and, after a few days, he learned that the orders were positive. I was forbidden to leave India.

Meantime I had given up my room, and, finding it already re-rented, I took another in a different quarter of the city. Next day a friend came to tell me that at half past three that morning the police had raided my old room and made a search of the whole house. A little later I got another message. The police had also gone to my room at the university with a summons, ordering me to report to the commissioner of police and to be ready for deportation to the Andaman Islands, a penal colony where political prisoners were being interned. Not finding me, they had searched my room and left the summons. All this was sufficiently disturbing. I spent the night without much sleep, debating what I ought to do. I finally decided to call on the commissioner of police and learn, if I could, what the trouble was.

Accordingly, at eleven o'clock the next morning I presented my summons and asked to see the commissioner. The clerk who took it away came back presently saying that the business concerned the office on Kidd Street and that I should report there. It seemed probable that the local authorities had no very incriminating evidence against me or that they thought I could not really be the person meant in whatever message they had received. So I set out for Kidd Street.

On the way, however, it occurred to me that, were I ever to have the benefit of sounder judgment than my own, I had better get it then; for, if it was decided at Kidd Street that I must be locked up, I should have precious little chance of consulting anybody or of acting upon what advice I might get. Instead of going to Kidd Street, therefore, I started for the college; but on the way I met someone who told me the police were waiting for me. So I turned homeward, and in the evening I went again to see Sir Asutosh Mookerjee. He received me with great kindness, and we spent a long time in trying to decide on the best course for me to pursue. Finally I said to him: "Your judgment is much better than mine, and I am ready to be guided absolutely by what you advise." He was silent for awhile and then replied: "I have been thinking what I should do if it were my problem instead of yours. I hope that in that case I should act as it would be fitting for a man to act. And so I feel that, if you value your manhood, you will not surrender and ruin your career."

> [This was the end of Ghose's association with the University. He fled Calcutta and joined the revolutionaries. A few months later, he again came back to Calcutta, and met Sir Asutosh, who positively advised him to leave Calcutta as "it has become too hot for him".]

Compiled by: **Anirban Kundu**

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[1] The British spelling of Krishnanagar.

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[3] Maharaja Sir Manindra Chandra Nandy (1860-1929).

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# List of Past and Present Teachers of the Department and Some Thumbnail Profiles

## Past Teachers of the Department

Debendramohan Bose
Phanindranath Ghosh
Satyendranath Bose
Sisirkumar Mitra
Bidhubhushan Ray
Durgadas Banerjee
Jatindranath Bhar
Syamadas Chatterjee
Arun Kumar Dutta
Prabahan Kemal Kabir
Sudhansu Datta Majumdar
Sibabrata Bhattacharya
Satisranjan Khastgir
Purnangshu Kumar Roy
Dwijendralal Bhattacharya
Chanchal K. Majumdar
Ashim Kumar Ganguly
Mihir Kumar Roy
Binayak Ghosh
Pradip Narayan Ghosh
Ramendra Kumar Poddar
Manoranjan Saha
Prasanta Kumar Bhattacharyya
Ramendra Kumar Kar
Asok Ranjan Thakur
Jogeshchandra Mukherjee
Sir Chandrasekhara Venkata Raman
Meghnad Saha
Susilkumar Acharyya
Brajendranath Chakrabarti
Hrishikes Rakshit
Pareshchandra Bhattacharya
Niraj Nath Dasgupta
Samarendranath Ghoshal
Basantidulal Nag Chaudhuri
Kamalaksha Dasgupta
Subodhnath Bagchi
Aparesh Chatterjee
Jyotirmay Das
Dilip Banerjee
Nityaranjan Pan
Santosh Kumar Sarkar
Utpal Chaudhuri
Arun Kumar Das
Kartick Chandra Das
Buddhadeb Bagchi
Dilip Sen
Asit Baran Sanyal
Priyabrata Roychowdhury
Tapan Kumar Das

## Present Teachers of the Department

Amitava Raychaudhuri
Gautam Gangopadhyay
Sourish Banerjee
Jayalakshmi Shamanna
Jayashree Saha
Indrajit Mitra
Subinay Dasgupta
Parongama Sen
Biswajit Ray
Anindya Datta
Sudipta Bandyopadhyay
Salil Kumar Biswas
Debnarayan Jana
Anirban Kundu
Abhijit Bhattacharyya
Aritra Banerjee

## Thumbnail portraits of some of our illustrious teachers who are no longer with us

Jatindranath Bhar

Niraj Nath Dasgupta

Syamadas Chatterjee

Basantidulal Nag Chaudhuri

Sudhansu Datta Majumdar

Prabahan Kemal Kabir

Satisranjan Khastgir

Samarendra Nath Ghoshal

Chanchal Kumar Majumdar

### Satisranjan Khastgir (1898-1973)

Satisranjan Khastgir obtained his Ph.D. (1924) and D.Sc. degrees (1926) from the University of Edinburgh, UK. His specialization was in Atmospheric Physics and Radio Engineering. He was Professor and Head, Department of Physics, Presidency College, Kolkata; Professor of Physics, Colombo University; Reader in Physics, University of Dacca; Professor and Head, Department of Physics, Banaras Hindu University; Khaira Professor and Dean, Faculty of Science, CU; and Head, Department of Physics, Bose Institute, Kolkata.

Khastgir worked on atmospherics, namely, the radio disturbances caused by natural sources such as lightning, electrical storms, etc. by means of electromagnetic waves. He made a significant contribution to ionospheric research. His research on electromagnetic wave propagation in the ionosphere is considered to be an extension of JC Bose's pioneering work on electromagnetic waves in the microwave region. He was a Fellow of Royal Society of Edinburgh and the National Academy of Sciences (India), Allahabad.

### Niraj Nath Dasgupta (1909-1999)

Niraj Nath Dasgupta got his Ph.D. from the University of London in 1938 and D.Sc. from the University of Kalyani, with a specialization in biophysics, biomedical science and electron microscopy. He was initially employed as Sir Taraknath Palit Professor of Physics in CU (1969-74) and Professor-in-charge, Electron Microscope Centre, CU (1974-80) before becoming Professor and Head, Biophysics Division, Saha Institute of Nuclear Physics, Kolkata (1951-69). He built and installed the first electron microscope in India and became a pioneer in its applications. For example, he did pioneering work in tracer studies on the uptake of radio-iodine in thyroid diseases and on the life-span of human leucocytes in leukaemia. He initiated electron microscopic research on bacterial chromosomes and on the morphology of the kala-azar parasite and Mycobacterium leprae. He further investigated the physical characteristics of haemoglobin molecules, and viral DNA molecules as well as their interactions with proteins and drug molecules.

Dasgupta was elected as General Secretary of the Indian Physical Society and served as a Member on the Executive Committee of International Federation of Societies of Electron Microscopy and also of the American Physical Society and Institute of Physics (London). He became the Founder President, Electron Microscope Society of India in 1962 and remained the President of the Indian Photobiology Society from 1969 to 1973. Niraj Nath built up an active school of biophysical research in Calcutta. He moreover served on the editorial board of Ultramicroscopy, in addition to editing a book named Electron Microscopy in Life Sciences. He served on the INSA Council during 1970-72. He was a Fellow of the Indian National Science Academy.

### Syamadas Chatterjee (1909-1995)

Syamadas Chatterjee ot his D.Sc. in 1946 from CU. His areas of specialization were Nuclear Physics, Cosmic Rays and Solid-State Physics. He was a teacher of the Physics Department of CU before moving to Jadavpur University, where he taught from 1956 to 1969. He was also a

Visiting Professor, Technical University, Munich, Germany (1963-66), a Senior Scientist, Indian Association for the Cultivation of Science (IACS), Kolkata (1970-77), Professor Emeritus (1977) and a Visiting Scientist at Variable Energy Cyclotron (BARC), Kolkata.

Chatterjee discovered the spontaneous fission of uranium simultaneously with and independently of Petrazhak and Flerov. He isolated Co-60 chemically for the first time from inactive neutron-irradiated Co-59 and extracted and purified He gas (99.98%) and other noble gases from natural gas emanating from thermal springs of India, like Bakreswar. He also fabricated a high pressure ionization chamber and proportional counter and suggested possibilities of Mossbauer effect by cooling in liquid helium.

Chatterjee started the SD Chatterjee Research Foundation in Kolkata and was its Director (1985-95). He was a Life Member of Royal Institution (UK), Institute of Electrical and Electronics Engineering (USA), American Physical Society, Instrumentation and Measurement Society (USA) and Laser and Electro Optics Society (USA). He was a recipient of Woodburn Medal of IACS (1948), the MN Saha Memorial Medal of Asiatic Society (1982), Institute of Electrical and Electronics Engineering Centenary Plaque (1984) and MN Saha Memorial Plaque of Indian Science News Association (1984). He was also a Fellow of New York Academy of Sciences.

**Jatindranath Bhar (1911-1980)**

J.N. Bhar got his D.Sc. from CU in 1939. His area of specialization was atmospheric physics. He was a teacher of the Physics Department before moving to the Radiophysics and Electronics Department of CU, where he was a Professor.

Bhar was the first to observe radio reflections from low heights of the atmosphere. He made the first comprehensive survey of ionospheric conditions in subtropical regions and their correlation with certain geophysical and geomagnetic phenomena. His explanation of the formation of the E-region of the ionosphere and its stratification has been a particularly valuable and original contribution to our knowledge of formation of the ionospheric layer.

Bhar contributed to several policies of the All India Council for Technical Education as a member of their Eastern Regional Committee. In addition he was on the Electronics, Materials and Components Research Committee (CSIR), Research & Development Committee of West Bengal and Executive Council, National Physical Laboratory. He was a Fellow of all the three science academies in India, namely, Indian Academy of Sciences, Indian National Science Academy, and National Academy of Sciences. He was also the vice-president (1970) of the Institution of Electronic and Radio Engineers (IERE) (London).

**Sudhansu Datta Majumdar (1915-1997)**

Datta Majumdar got his M.Sc. from this Department and had his D.Sc. From CU in 1962, one of his examiners being John A. Wheeler. Beginning with a stint in the Palit Laboratory of Physics, Calcutta University, from where he did his famous work (Phys. Rev. D 72, 390 (1947)), now known as the Majumdar–Papapetrou solution, he was appointed Lecturer in Physics in CU in

1951 and subsequently became a reader in 1960. He was in the Department till 1965. During 1956-57, he went to Cambridge University on an educational tour to interact with P.A.M. Dirac.

He worked in the fields of General Relativity, Electrodynamics, Group Theory and Spectroscopy.

### Basantidulal Nag Chaudhuri (1917-2006)

B.D. Nag Chaudhuri had his M.Sc. from Allahabad University where he got Saha as a teacher, and got his Ph.D. in 1940 from the University of California, Berkeley, with Ernest Lawrence. He was a teacher of the Department from 1942 to 1959, the last six years as the Palit Professor of Physics, a chair just vacated by Saha. After Saha's untimely demise in 1956, Nagchaudhuri became the Director of SINP, first as officiating (1956–59) and then as permanent (1959-67). He was a member of the Planning Commission and the Vice-Chancellor of JNU. He was also involved in a number of educational committees set up by the Government. He also served as a Member of the Scientific Council of the International Centre for Theoretical Physics, Trieste, Italy (1976–84) and was a Member and Chairman of the International Advisory Panel, East-West Centre, Honolulu, Hawaii. He was also a member of many learned societies.

He was an experimental nuclear physicist, with interests in nuclear isomerism, artificial radioactivity, and Cerenkov effect. He was a member of Indian National Science Academy and Indian Academy of Sciences, and became a Padma Vibhushan in 1975.

### Samarendra Nath Ghoshal (1923-2007)

Samarendra Nath Ghoshal did his M.Sc. from CU and Ph.D. from University of California, Berkeley. He carried out research under M.N. Saha and Emilio Segre. His field of specialisation included experimental nuclear physics and mass spectroscopy. His name is forever attached with Ghoshal's experiment, the first and definitive experiment that vindicated the theory of compound nucleus.

He taught at University of Lucknow, Saha Institute, and Presidency College, before moving, for the final years of his career, to Calcutta University as the Khaira Professor of Physics. He was also the Principal of Presidency College at a very tumultuous time of student politics in West Bengal.

He was an N.R.C. Fellow of the McMaster University, Canada, and served on numerous academic committees in India.

### Prabahan Kemal "Pasha" Kabir (1933-2004)

P.K. Kabir, son of the minister of education in Nehru government, Humayun Kabir, was known to his family and friends by his nickname Pasha. He had his M.Sc. from Delhi and Ph.D. from Cornell, where his work was on the Lamb shift in helium and his thesis advisers were Hans Be the and Edwin Salpeter. After completing his Ph.D, Kabir spent a year (1956-57) at the Institute for Advanced Study at Princeton, when parity violation was large on the agenda, and the following year (1957-58) at Birmingham University in the UK with Rudolf Peierls.

Kabir joined CU as the Sur Reader and stayed for two years, and then moved to the US as a junior faculty member at Carnegie-Tech. He then went to CERN for two years as a visiting scientist (1963-65), followed by six years on the staff at the Rutherford Laboratory (1965-71) in the UK. He returned to the US in 1971 as professor at the University of Virginia.

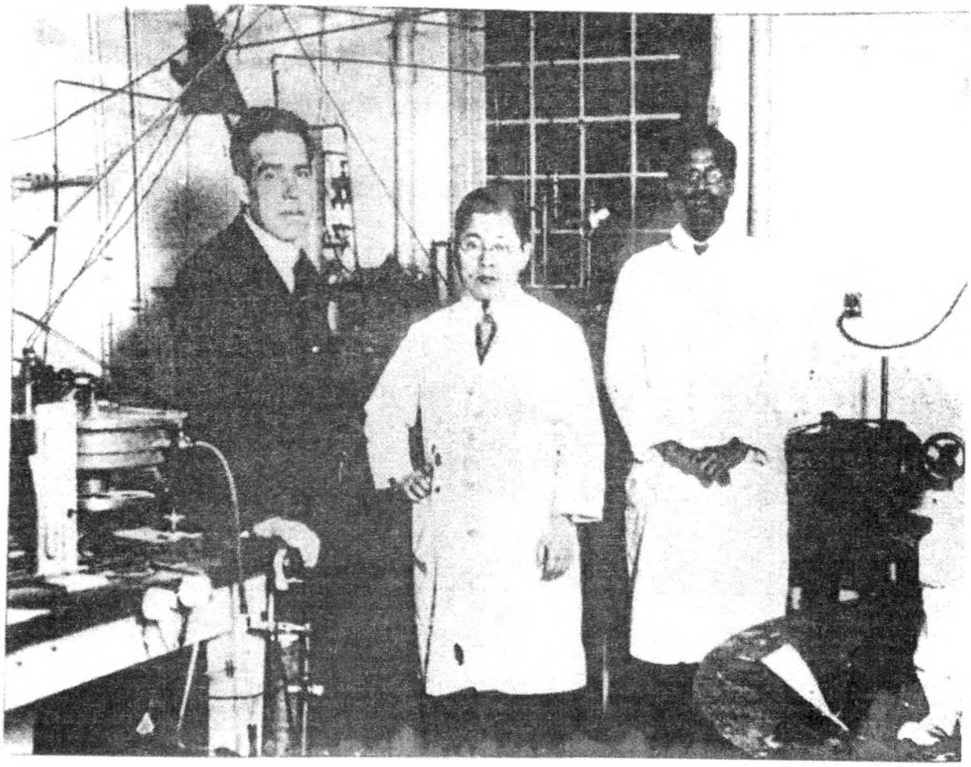
Kabir's many contributions in physics centred on symmetry and symmetry violation, especially charge-parity (CP) and time-reversal (T) violation. He edited the book Developments in the Theory of Weak Interactions, which reprinted all the important contributions to the field up to 1963, and was author of The CP Puzzle (1966), which remains widely quoted as a detailed account of the neutral kaon system. His later description of T violation in the kaon system, without assuming CPT invariance, has been important in stimulating experimental work. Kabir realized that T violation implies the breaking of detailed balance, and in 1970 he introduced a parameter to describe this in the kaon system; the Kabir parameter was at last measured 30 years later. His name is also given to an important theorem in field theory: the Feinberg-Kabir-Weinberg theorem, the first example of a cancellation of a flavour-changing neutral current (muon to electron).

### Chanchal Kumar Majumdar (1938-2000)

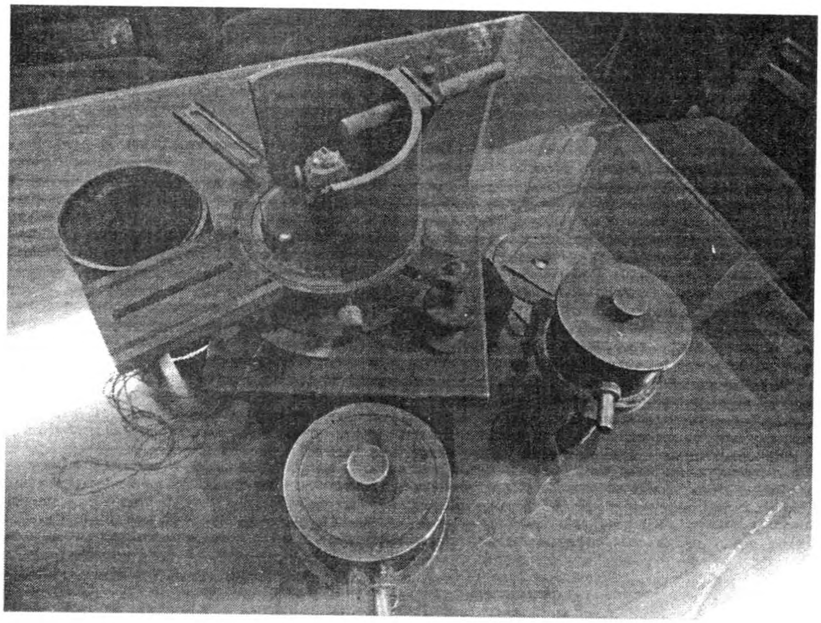
Chanchal Kumar Majumdar got his Ph.D. from University of California, San Diego, in 1965 and specialized in physics of condensed matter. He served as the Associate Professor, Tata Institute of Fundamental Research, Mumbai (1966-75); Palit Professor of Physics, CU (1975-82); Head, Department of Magnetism, Indian Association for the Cultivation of Science (1982-87); and Director, SN Bose National Centre for Basic Science (1987-2000).

Majumdar had worked on a number of important topics in condensed matter physics, like the effective mass of positrons in metals, the two dimensional angular correlation of positron annihilation radiation, the three-magnon bound state equation, the stress relaxation in soda-lime glass, the critical isotherm of the Ising model and of the Lennard-Jones gas and corrosion in iron and determination of $Fe^{2+}/Fe^{3+}$ ratio in iron minerals by Mossbauer effect. Majumdar made an important contribution in the area of disordered solids. Majumdar pioneered computational studies in condensed matter physics in India. He and his coworkers applied state-of-the-art computational techniques to a variety of important problems like electronic band structure calculations of alpha and gamma-cerium, lower bound to the ground state energy of the Heisenberg Hamiltonian on a triangular lattice and the thermodynamic and dynamic properties of finite-sized spin chains.

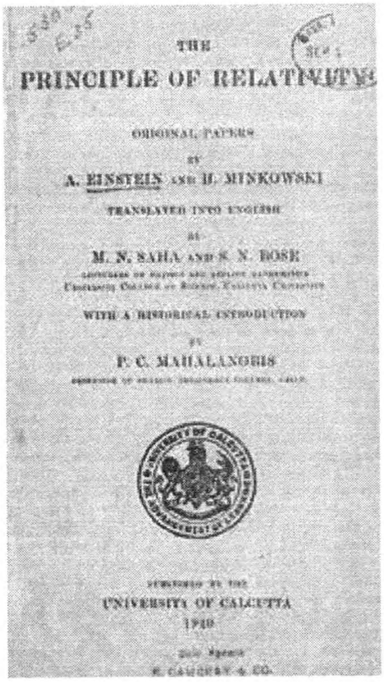
Majumdar was a Member, Indo-US Subcommission in Physics, Indian Commission for Cooperation with Unesco, Commission on Planning Higher Education in West Bengal, UGC Physics Panel, and physical research advisory committees of CSIR and DST. He received the SS Bhatnagar Prize (1976); MN Saha Medal of Asiatic Society (1978); PA Pandya Award of Indian Physics Association (1979); UGC National Lecturer (1978-79); MN Saha Award of UGC (1983) and SN Bose Medal of INSA (1989). He was a Fellow of all three science academies in India as well as American Physical Society.



B.B. Ray (R) with Niels Bohr (L) and Yoshio Nishina (C) [Courtesy: Niels Bohr archive]



The X-ray camera built by S.N. Bose, still in the Department.



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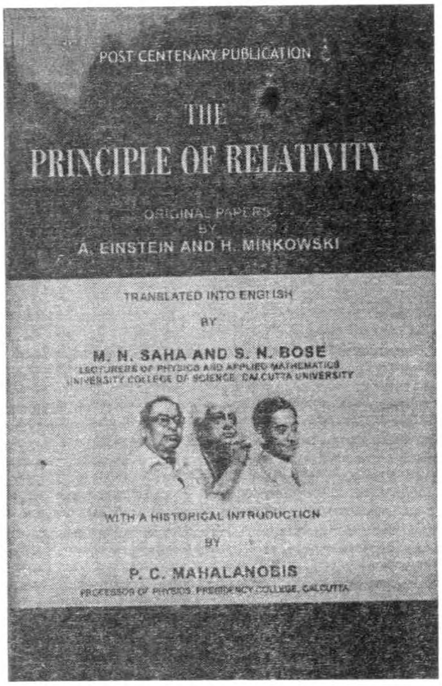

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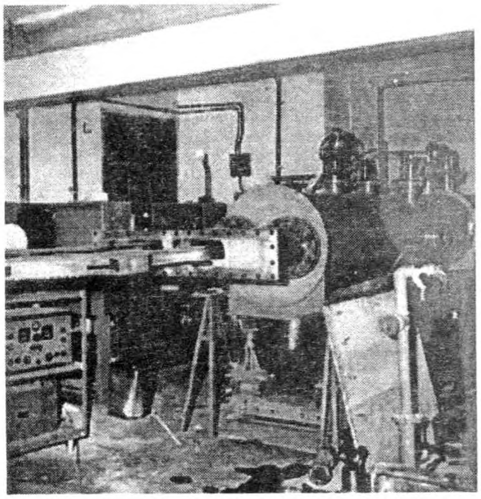
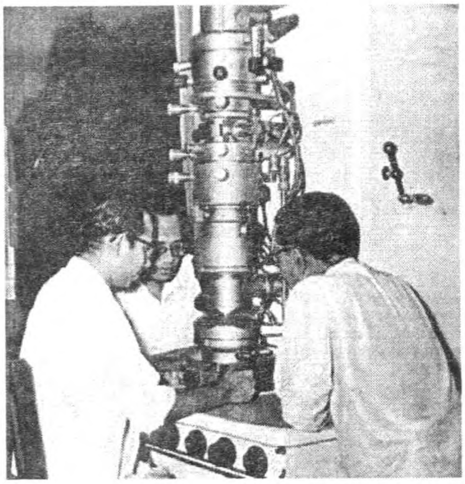
The English translation of the Relativity papers by Saha and Bose.
(L): The 1920 CU edition; (R) The recent reprint in 2006.





The dee of the original cyclotron built by Saha's group (L) and the 100 kV electron microscope (R).

# Sisir Kumar Mitra FRS—Scientific Achievements in National and International Context

**Rajinder Singh**
University of Oldenburg, Germany

## Introduction

In the first half of the 20th century, only three Indian physicists were asked by the Nobel Committee to send proposals. Sisir Kumar Mitra (1890-1963) was one of these physicists. He was associated with renowned institutions like Indian Association for the Cultivation of Science, Asiatic Society of Bengal, Indian National Science Academy and University of Kolkata. To my knowledge, very few short papers are written on his life and work.[1] Less known fact is that Mitra proposed a new periodic element chart (Fig. 1).[2]

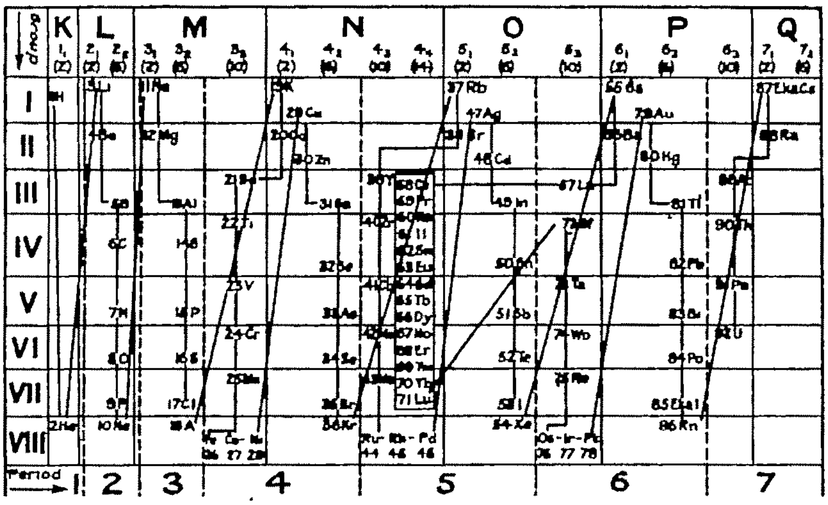


Fig. 1: The periodic classification of the elements as proposed by S.K. Mitra (Courtesy Phil. Mag. 11, 1927).

Last year I wrote his biography "Nobel Prize Nominator Sisir Kumar Mitra F.R.S. –His Scientific Work in International Context."[3] While commenting on the book, Prof. S.C. Roy, Editor-in-Chief "Science and Culture" stated: "..., it is true that Sisir Kumar Mitra is less discussed, inadequately publicised and sparingly celebrated. Rajinder Singh noticed this lacuna and this book originated from his passion to fill this gap; ....."[4] And further:

> "Sisir Kumar Mitra is known as the initiator of wireless technology and ionospheric research. But his works on diffraction of light, on which he started working with Sir C.V.

> Raman and led to his obtaining the D.Sc. degree from Calcutta University, is less known even to the scientific community in India. Rajinder Singh has included all his research activities in painstaking detail, which I believe will satisfy all readers- from the casual to the serious. More interested readers will benefit from the complete set of bibliographies presented by the author."[5]

Unfortunately the book is not available in India. Apart from that it is very expensive. Thus, at the occasion of the 100th anniversary of the Department of Physics–University of Kolkata, I thought it worth to reproduce main parts of "Nobel Prize nominator Sisir Kumar Mitra F.R.S." and make available to readers in his '*Alma Mater.*' In the present article I have attempted to discuss: (a) His scientific work and its reception by the international scientific community. (b) Mitra's role as Nobel Prize nominator. (c) His induction into the Fellowship of the Royal Society of London.

To start with a short biography is given, which is based on above referred to articles.

**Sisir Kumar Mitra F.R.S. – Some Biographical Facts**

Sisir Kumar Mitra F.R.S.[6] (Courtesy, University of Kolkata, Hundred Years of the University of Calcutta, 1957)

Sisir Kumar Mitra was born on Oct. 24, 1890, at Konnagar, Calcutta. His father, Joy Krishna Mitra, was a school teacher. His mother, Sarat Kumari, was a doctor at the Lady Dufferin Hospital, Bhagalpur. Mitra studied at the Bhagalpur District School and T.N.J. College. At the time of his father's death, Mitra had yet not finished his F.A. (First Arts) examination.

1908: Joined Presidency College Calcutta
1910: B.Sc., University of Calcutta
1912: M.Sc. Physics, University of Calcutta; Gold Medal
1913-1915: Lecturer–T.N.J. College Bhagalpur; Christian College Bankura
1914: Married Lilavati Devi Biswas
1916: Lecturer–Science and Technology College, University of Calcutta; Began research under C.V. Raman
1919: D.Sc., University of Calcutta. Thesis on "The interference and diffraction of light"
1920: Gave a new geometrical theory of the diffraction-pattern in heliometer
1920-1923: D.Sc., University of Sorbonne, Paris. Thesis on "The determination of standard wave length in the region of 2000 to 2300A° "
1923: Khaira Professor of Physics, University of Calcutta; Initiated the teaching of wireless technology at the graduate level
1924-1948: Chairman, Radio Research Communications
1925: Established Wireless Laboratory and a radio transmitting station
1929, 39, 54: Nobel Prize nominator
1934: Sectional President for Physics and Mathematics–Indian Science Congress

Association (I.S.C.A.); Secretary–Indian Association for the Cultivation of Sciences

1935: Experimentally proved the existence of the D-layer in atmosphere; Foundation Fellow, National Institute of Sciences, India (Today known as Indian National Science Academy–I.N.S.A.); King George V Silver Jubilee Medal; Co-editor, "Science and Culture"

1935, 1938: Local Secretary - I.S.C.A.; General Secretary (1939-1944)

1935-1955: Ghosh Chair of Physics

1936: A six month period in U.K., during which, Mitra visited different laboratories working on wireless technology; and sought support from the British scientific community for establishing Radio Research Board in India.

1937: Member of the editorial team of the "Indian Journal of Physics and the Proceedings of the I.A.C.S."

1938: Officer of the Most Excellent Order of the British Empire (O.B.E.); Explained the origin of the E-layer in ionosphere

1943: Joy Kissen Mookerjee Gold Medal–I.A.C.S.

1943-1944: Vice President–I.N.S.A.

1943-1948: Chairman, Radio Research Committee

1944-1945: Visited U.K. and America as a Member of the Indian Scientific Mission

1945: Monograph "Active Nitrogen–A New Theory", Indian Press Ltd., Calcutta

1946: Explained the Appelton magnetic control anomaly in $F_2$-layer

1947, 1952: Published "The Upper Atmosphere", Asiatic Society of Bengal, Calcutta

1948: Natural History Secretary (Physical Sciences), Asiatic Society of Bengal

1949-1950: Ordinary Member of the Council of the I.A.C.S.

1949-1955: Professor, Institute of Radio Physics and Electronics, University of Calcutta

1951-1952: President, Asiatic Society of Bengal

1953-1954: Vice President–I.A.C.S.

1954: Member of Council–National Institute of Sciences, India

1955: Professor Emeritus

1955: President, I.S.C.A.

1956: Indian Science Congress Medal of the Asiatic Society of Bengal

1956-1962: Administrator of the Board of Secondary Education in West Bengal

1958: Fellow Royal Society London

1959-1960: President I.N.S.A.

1961: Sir Deva Prasad Sarvadhikary Gold Medal of the University of Calcutta

1962: Corresponding Member of the International Academy of Astronautics

1962: Presidential Award Padmabhushan; National Research Professor

1963: Died, August 13

## S.K. Mitra - Research in Optics

Mitra started under J.C. Bose as research scholar. However, due to financial problems, he left to work as a lecturer.[7] Later, he took on a better paid position as Rashbehary Ghosh Research Scholar at the University of Calcutta.[8] Mitra enhanced Raman's previous work on diffraction of monochromatic light in an oblique single slit. Experimentally, he (C.V. Raman) found that the pattern on both sides of the central fringe was asymmetrical. Also, he gave an expression to calculate the intensity. Following this, he made a quantitative study of the oblique diffraction phenomenon. Some of the conclusions were:[9]

i. "The illumination at the points of minimum intensity in the diffraction pattern is zero at all angles of incidence, and the positions of the minima are given by the formula $\delta = \pm\pi$, $\pm 2\pi\partial$, $\pm 3\pi, \ldots$, where $\delta = \pi a \lambda^{-1} (\sin \imath - \sin \theta)$, "a" being the width of aperture, $\lambda$ the wave-length, and, $\imath$ and $\theta$, the angles of incidence and diffraction respectively; the fringes are wider on the side on which $\theta > i$ and their number is limited on that side, as $\theta$ cannot be greater than $\pi/2$.

ii. ...the intensities at corresponding points on either side of the central fringe for which the values of $\delta$ are numerically the same are *not* equal (emphasis in original)."

iii. The observed distribution of intensity ...fit in with the theoretical formula, if the latter is multiplied by a factor proportional to the square of the cosine obliquity, which, of course, is not the same at all points in the diffraction pattern."

Mitra's objective was to assess, whether Raman's deductions were valid for two or more parallel slits lying in the same plane. He performed experiment with two apertures, with 1.446 cm distance between them. The experiment was done for three different angles. Mitra checked the validity of the following formula for the minima between the successive interference patterns: $\sin\theta_1 - \sin\theta_2 = \sin\theta_2 - \sin\theta_3 = \ldots$He showed that Raman's formula is valid under these conditions, and the position of the interference minima can be given by usual method, namely, $\delta = \pm\pi/2, \pm 3\pi/2, \pm 5\pi/2, \ldots$, where $\delta = \pi (a + b) (\sin i - \sin \theta)\lambda^{-1}$ with "b" as distance between the apertures.

Mitra continued this work in detail, which later led him to contrive a geometrical theory of the diffraction pattern observed in heliometer.

### *A New Geometrical Theory of the Diffraction Figures in a Heliometer*

In 1883, Ernst Heinrich Bruns (1848–1919), Germany, produced a formula to calculate the intensity of light at any point near the focus of a heliometer objective.[10] In 1896, his countryman, Arnold Sommerfeld (1868-1951), wrote on the theoretical concept of the diffraction of light.[11] Later, Horatio Scott Carslaw (1870-1954) and Horace Lamb (1849-1934) gave simpler theories. Mitra had pointed out that the work of the authors has not been tested experimentally. Sommerfeld and Paul Drude (1863-1906) had completed experiments with the semi-infinite screen. Based on the experimental results, Mitra stated that "*when the screen is held very obliquely in the path of the incident waves,* the rigorous treatment gives results differing from those of the approximate theory *even in regard to small angles of diffraction* (emphasis in original)."[12] Mitra was of the opinion that the present, state-of-the-art study of diffraction providing a true picture of the phenomenon cannot be claimed to be 100% accurate. He studied the diffraction phenomenon for elliptic apertures, semi-circular apertures, and apertures with undulating or corrugated boundaries. Mitra's main point of interest was a "special" figure observed by him, as it dealt with pattern observed in heliometer objective. He noted:

> "...there is a long horizontal trail of light proceeding to a great distance in either direction at right angle to the diameter of the semicircle. Crossing this, we have numerous streamers of light, one of which is parallel to the diameter and the others from roughly a system of hyperbolic arcs symmetrical about the horizontal axis. The streamers are brightest to the left of the diameter, but they may also be seen very faintly to the right of it. The pattern thus shows many strikingly resemblances with the Fraunhofer pattern at the focus of the heliometer objective, which is described by [Philip Francis] Everitt...."[13]

In 1910, P.F. Everitt, U.K., reported that "a problem which has attracted the attention of more than one astronomers and mathematicians but had not yet been overcome, has been solved,...."[14] Everitt applied the best available mathematical tools and numerically determined the exact nature of heliometer diffraction patterns. There was agreement between the numerical and experimental results. Mitra's assessment of Everitt's work was that: "...the method adopted by him is unsatisfactory from a physical point of view, as it is essentially numerical in spirit, and leaves the reader without a clear conception of how precisely the peculiar configuration of the pattern arises from the semi-circular form of the aperture."[15] Apart from that the "work was also of somewhat limited scope, as the calculation of intensities was confined to a relatively small region surrounding the position of the geometrical focus." Mitra founded a simpler method. About its features he stated:[16]

- "...the theoretical determination of the form of the diffraction figures in the heliometer can be carried out without appreciable loss of accuracy by a method which is geometrical in character and is far less laborious than that adopted by Everitt.
- ...it has ...the advantage of enabling the form of the pattern to be readily determined for a region of any desired area surrounding the focus.
- The geometrical form of the pattern deduced by this method is in close agreement with experiment, and shows certain features at large angular deviations from the focus which were unsuspected by Everitt and which indeed make necessary a modification of the description of the diffraction-figures published by him.
- The work has also brought to light another important feature not mentioned by Everitt, that the fluctuations of intensity along the long horizontal ray that appears crossing the pattern decrease both relatively and absolutely at large angular deviations."

To determine the position of the interference pattern, Mitra did not begin with the usual assumption of a surface area integral, but a line integral. This was reduced to finite number of points of sources of light. The author wrote:[17]

> "The position and intensity of these point-sources on the boundary is generally not fixed, but varies with the direction of the diffracted light. In other words, corresponding to each point in the focal plane at which the diffraction pattern is formed, we have certain points on the boundary which principally contribute to the luminous effect at the point of observation, and the whole of the diffraction pattern may be simply regarded as an interference pattern clue to a finite number of light-sources of *variable position* situated on the boundary of the aperture" (emphasis in original).

For the calculation of the intensity in the diffraction pattern in the two principal directions, that is, perpendicular and parallel to the diameter, Mitra assumed that a semi-circle consists of narrow strips, parallel and perpendicular to the diameter. He gave the following expression for the disturbance due to the semi-circular aperture to calculate the intensity for any value of angle $\delta$ : $2\delta^{-1}(2/\pi\delta)^{1/2}\sin(\omega t + 3\pi/4 - \delta - 3/8\delta) + 4/\pi\delta\sin(\omega t - \pi/2)$. He stated:[18]

> "It is obvious that of these two terms, the latter varying as $\delta^{-1}$ ultimately predominates for increasing values of $\delta$. The intensity in the diffraction pattern in the direction perpendicular to the diameter thus ultimately varies as $\delta^{-2}$; while in direction parallel to the diameter, it decreases much more rapidly in the ratio of $\delta^{-3}$. Thus, we have in the diffraction pattern a long bright ray running perpendicular to the diameter of the semicircle. Further, in the direction of the bright ray, not merely do the absolute intensities diminish, but the ratio of the intensities at maxima and minima also tends to approach unity, in other words, the fluctuation of intensity along the bright ray tends to diminish both relatively and absolutely."

He then proceeded to the general configuration of the pattern. His results were in the same range of degree of accuracy as those of Everitt's (Fig. 2)

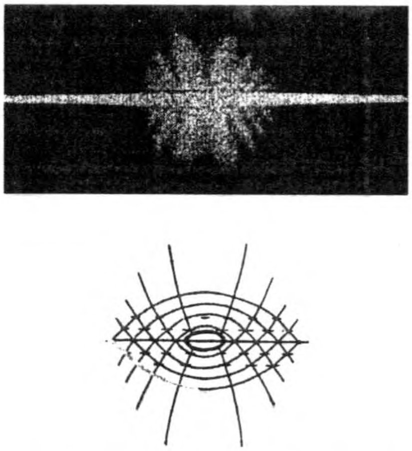


Fig. 2: General configuration of the pattern–A comparison of experimental and theoretical observations (Courtesy I.A.C.S. 6, 1920).

Mitra gave an expression for the amplitude at any point on the focal plane. He calculated the values of intensity, H, for various values of θ and δ in the focal plane. When comparing them with Everitt's values, he found that they agreed. With long exposure time he observed unknown features of diffraction. He stated: "The pattern roughly consists of two sets of parabolas (…) branching in opposite directions. These features do not clearly appear in the relatively small region covered by the pictures of previous workers. Another important feature…, is that the fluctuations of intensity along the long bright ray that appears crossing the pattern decrease both relatively and absolutely at large angular deviations." And further: "This method greatly facilitates numerical computation of the light intensity for small as well as for very large angles of diffraction (the latter being almost impossible to obtain by the ordinary treatment), and gives results, which are for all practical purposes, as accurate as that obtained by elaborate mathematical formulae."

In the next communication, Mitra tested his theory for a segment of the circular shape. Fig. 3 shows a remarkable agreement between the theory and experiment.[19]

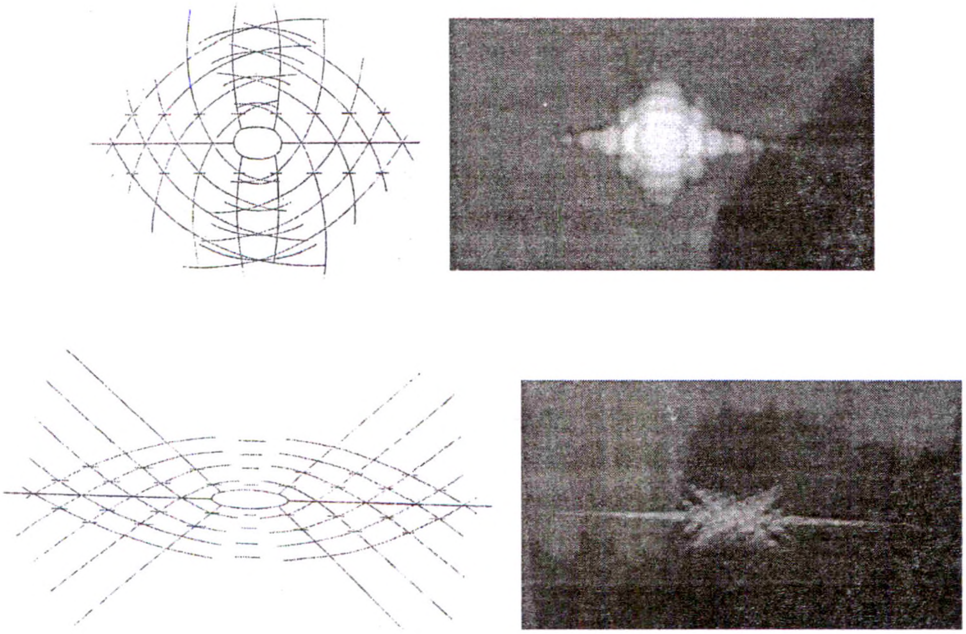


Fig. 3: Diffraction pattern based on Mitra's theory for circular aperture. Above: Circular aperture greater than a semi-circle; Below: Circular aperture smaller than a semi-circle
(Courtesy University of Calcutta, Sir Asutosh Mookerjee Silver Jubilee, Vol. II, 1922).

Based on the above mentioned research on light diffraction and interference Mitra obtained D.Sc. degree from the University of Calcutta. In 1920 he went to France for further studies.

### *Work on Optics in France*

In France, Mitra worked in the laboratories of Charles Fabry (1867–1945)–one of the discoverers of ozone-layer, and Marie Sklodowska-Curie (1867–1934)–a pioneer of radioactivity. There he took second D.Sc. Degree. The abstract of his publication: "Determination of spectroscopic standard wave-lengths in the short wave-length region"[20] was reported in the "Journal of Chemical Society." It stated that Mitra by applying Fabry-Perot interferometer method determined: "the following wave-lengths in the arc spectrum of copper below $\lambda$ 2374A°., where standard determinations have hitherto been lacking: 2369.891, 2303.134, 2276.261, 2242.622, 2218.107, 2189.631, 2148.897, 2126.047, and 2112.105A°. In addition, the standard line $\lambda$ 2334.816A° in the arc spectrum of tin has been determined. In general, the experimental values differed from the respective mean values given by less than ±0.002A° and never by more than ±0.003A°."[21]

### *A New Method to Photograph the Interrupted Light at High Frequency*

In the October 22, 1927 issue of "Nature" the Australian physicist, Kerr Grant (1878–1967), reported that, at his suggestion in the laboratory of the Adam Hilger and Co., London, the following experiment was performed. A beam of light was passed through a quartz piezo-electric resonator, which was placed between the crossed Nicol prisms. By applying an oscillating voltage from a valve circuit, the crystal plate was excited to resonant vibration. Strongly transmitted light, with regular flashes, was examined by a rotating mirror. With a high speed camera, it was attempted, without success, to photograph the flashes passing through a crystal.[22] Mitra and D. Banerji repeated the experiment and developed a method, which made it possible to photograph the effect due to interruption of light at high frequency.[23]

## **Radio Physics and the Radio Research Board**

### *S.M. Mitra's Scientific Work in France on Radio Communication*

In France, Mitra worked with the French radio communication scientist Camille Gutton (1872–1963). Mitra's papers were read before the Paris Science Academy by Gustave Auguste Ferrié (1868–1932)—an expert of wireless technology and an army officer. For military purposes, he developed mobile transmitters. Thus, there cannot be doubt that Mitra was well aware of the use of this technology in military and civil fields.

In 1902, Guglielmo Marconi (1874-1937) published an article in which he stated: "The present note bears upon the special manner in which a core or rod of iron or steel placed in a varying magnetic field is affected by high-frequency oscillations transmitted from considerable distances. ...The detector which I am about to describe is, in my opinion, based upon the decrease of magnetic hysteresis, which takes place in iron when, under certain conditions, it is exposed to the effect of high frequency or Hertzian waves."[24] In 1923 this paper was referred to by Mitra in the publication: "The demagnetisation of iron by electromagnetic oscillations."[25] The conclusion of Mitra's results was that "the demagnetization increases as the frequency of the oscillations is lowered."[26] Mitra's paper was read before the Science Academy by G.A. Ferrié on April 30, 1923. His next article in co-operation with C. Gutton and V. Ylöstalö was "On the high-frequency discharge in rarefied gases."[27] For experiment they took dry gas. The frequency range was between 50 and 2,140,000 Hertz. They found that "the potential varied with the frequency, and for tubes with internal electrodes the difference of potential always increased with the frequency; for tubes with external electrodes the pressure of the gas affected the relation between potential and frequency."[28] As the publication shows, Ferrié read this paper before the Academy on June 25, 1923.

During his stay in France, Mitra decided that, upon his return to India, he would start his workings on wireless communication in Calcutta. As literature suggests, before leaving for India, he wrote a letter to Asutosh Mukherjee (1864–1924), Educator and Vice Chancellor of the University of Calcutta, and revealed his plan.[29]

### *Establishing Wireless Laboratory at the University of Calcutta*

In the end of 1923, highly motivated, Mitra returned to the University of Calcutta where he was offered the Khaira Professorship Chair of Physics. He initiated the teaching of wireless at the graduate level and also established the Wireless Laboratory and made a radio transmitting station.[30] Most of his time was spent in management rather than scientific research and publications. Not surprisingly, between 1923 and 1930 there were not many publications from him. Once the laboratory was established, the research work was started under his guidance. According to my opinion Hrishikes Rakshit (1906-1991) was his first associate. An important contribution of "Mitra's School" was the "Radio field-strength survey of the city of Calcutta and its suburbs."[31] It was painstaking work carried out by Rakshit. To take the data he travelled about 1000 miles and took 200 readings. He studied the changes in field strength with regards to the distance and made a map. He measured the change of field strength with the distance and the diminution of field strength without absorption by the intervening media. He prepared a "radio field-strength contour map of Calcutta and its suburbs."[32]

### *Study of Thermionic Current and Valves*

In 1919, John Ambrose Fleming (1849–1945), the inventor of the vacuum tube or thermionic valve, justified the importance of his book as follows: "The thermionic valve and its various derivatives, such as the three-electrode amplifier and also the thermionic oscillation generator, have become such valuable appliances in wireless telegraphy that it would seem to be an advantage to collect into a single volume a brief summary of knowledge and practice connected with them for the assistance of practical radiotelegraphists."[33]

Mitra understood the importance of subject and started taking interest.[34] In 1901, Owen Willians Richardson (1879–1959) had shown that current from a heated wire increases exponentially with the temperature. For metals he gave an equation to calculate the number of electrons emitted per unit area in a unit time. It was later named as Richardson's law. It has been acknowledged that, depending upon the temperature and surrounding gas, a heating wire would emit positive or negative electricity. "Mitra's School" published on the space charge between a hot cathode and parallel anode. With regards to the objective of the experiment Rakshit wrote: "The case of altered distribution of electron density when a current flows between the cathode and the anode, though often met with in practice, has not received adequate attention from workers in this field."[35] For the thermionic current between a plane-heated cathode and a parallel anode he calculated the distribution of electron density. He gave numerical result for a typical case. He showed that when current flows, the electron density diminishes immediately near to the hot surface.

The ionized atmosphere is an important factor in the propagation of radio waves. As a result, various authors studied the changes in conductivity and the dielectric constant of a gas due to electrons and ions. Also, measurements were made on the changing of dielectric constant at various frequencies. Mitra and Bhabani Charan Sil, Khaira Research Scholar in Physics, addressed that little had been said on the change in the conductivity with reference to the frequency. They decided "…to investigate, …, the change produced in the conductivity of a space containing free electrons and bounded by two electrodes (as is usually found in a thermionic valve) when a high-frequency E.M.F. [electromagnetic field] is applied across the electrodes."[36] Their experiments on the variation of conductivity of the plate grid space of a triode valve within the frequency range $10^7$ to $6\times10^7$ Hertz showed that while going from the lower to the higher frequencies the conductivity can decrease by more than 100 per cent.[37] Their experimental results were in agreement with the theory.

It was well known that the signals sent by transmitter is reflected by the atmosphere are sent back to receiver on the earth. Why are the waves reflected back? The accepted idea was that "the ions in the Heaviside layer make the speed of propagation of the waves greater in that layer than in the ordinary air below and thus bend the waves round the earth by a process of refraction."[38] Mitra and H. Rakshit showed that the bending of light beam is observable under laboratory conditions.[39]

### *Radio Research Board—A Difficult Birth*

From his work on radio communication and ionosphere Mitra judged the importance of telecommunication technology. In 1935 at the occasion of the opening a symposium of the National Institute of Sciences, India, Mitra delivered a lecture on: "Report on the present state of our knowledge of the ionosphere." The journal, "Nature", admired this work and stated that much has been done in the field since 1920s. But "those whose main interest lies in other fields find it increasingly difficult to maintain an up-to-date knowledge on the ionosphere, and particularly to keep a clear perspective view of the progress which has been achieved and of its bearing on other fields such as meteorology and geophysics. It is here that Prof. S.K. Mitra has come to our rescue …"[40]

On January 30, 1936, Mitra delivered a lecture before the Maxwell Society at King's College London. He spoke about the importance of studying the atmosphere in India, as the geographical and climate conditions are different than in the U.K. and U.S.A. Mitra stressed the cooperation between different countries and institutions.[41] In U.K. he visited prominent scientists and their laboratories.[42] On May 5, 1936, in London scientists from U.K., Australia, and Canada stressed the importance of a Radio Research Board in India.[43] Richard Arman Gregory (1864-1952), editor of "Nature", expressed his views and later wrote an editorial on the subject.[44] Mitra told the public that though 10 years ago the research was started in India at Universities. Contrary to U.K., we are working alone as we have no co-operating Governmental bodies like the Air Ministry, the Meteorological and Postal Departments. Apart from that, we do not have adequate funds. "Nature" in its January 1937 issue, reported the problems the two researchers [Mitra and M.N. Saha] were facing.[45]

Unfortunately, the progress in this direction was very slow. In 1940 India had nine medium-wave and five short-wave broadcasting stations.[46] Mitra called the policy of the Government of support broadcasting, half-hearted.[47] He provided some suggestions in order to improve the situation, such as the formation of a Central Broadcasting Advisory Council, Central Programme Board, a Radio Research Board, and lower direct consumer cost to promote increased household presence.[48] Mitra's dream was fulfilled as in 1942 the Radio Research Committee was established. In 1945 the Committee submitted a plan for the establishment of an Institute. Shortly before independence, the All India Council of Technical Education approved a plan, which, in 1949, converted the Wireless Laboratory to the Institute of Radio Physics and Electronics (Fig. 4). Mitra became its Head and maintained the position until his retirement in 1955.

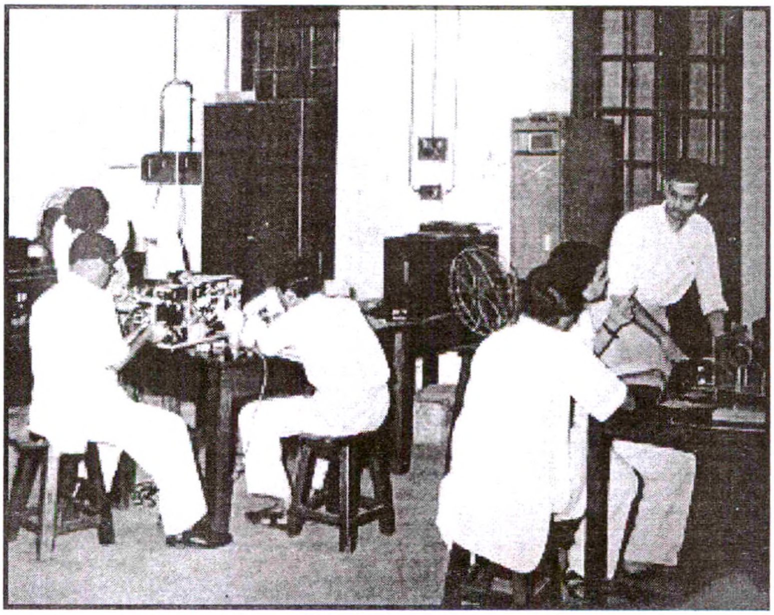


Fig. 4: Radio Physics and Electronic Laboratory
(Courtesy University of Kolkata, Hundred Years of the University of Calcutta, 1957).

## S.K. Mitra's School and the Study of Ionospheric Layers in Calcutta

So far, the initiation of the ionosphere research in India is concerned, according to Saha, credit goes to S.K. Mitra.[49] Prior to the application of the rockets and satellites for the studies of the atmosphere, either balloon-flights or radio waves were used. As we have seen above "Mitra's School" was well-versed with the implementation of radio waves.

In the late 1890s, with wireless technology, it was possible to send and receive radio signals at long distance. However, the question remained: what is the medium of propagation of the radio waves? In 1902, in the U.S.A., Arthur Edwin Kennelly (1861–1939), and nearly at the same in U.K., Oliver Heaviside (1850-1925), speculated an electrically conducting layer in the atmosphere which reflects the signals back to the earth. About two decades later, the experimental proof of its existence was given by Edward Victor Appleton (1892–1965) and his student M.A.F. Barnett.[50] In 1927, E.V. Appelton, while studying the Heaviside layer, reported to have observed a new ionized layer at the height of 250 km to 350 km.[51] He branded it the F-layer.

In the U.S.A., in 1925-1926, Gregory Breit (1899-1981) and Merle Anthony Tuve (1901-1982) developed a method to estimate the height of the ionized layer. This was based on the fact that radio-frequency pulses, for a very short duration, were sent from a transmitter. The pulses reached the receiver in two ways; one being along the earth and the other through reflection from the ionosphere. The receiver recorded two pulses—one direct and the other, an echo of the first. From knowledge of the time interval between the two, the height of the layer was calculated.[52] In a short note to "Nature", Mitra *et al.* reported a method which made possible the use of transmitting aerial as receivers for recording wireless echoes at the transmitting station.[53]

### *The Study of the Kennelly-Heaviside- and Appleton Layers in Bengal*

In the beginning of 1931, under the guidance of Mitra, H. Rakshit started study of the E-layer (Heaviside- or Kennelly-Heaviside layer) under subtropical conditions.[54] Mitra and Rakshit, by applying the wireless echoes delay method, found the height of the E-layer 80 km and that of the F-layer (or Appelton layer) 250 km. The transmitter was installed at the Wireless Laboratory, University College of Science; whereas the receiver was at a distance of 3.8 km from the college. For the second series of observations, the receiver was carried on a small motor-bus. They made measurements with wave-lengths of 42, 50, 75 and 80 meters. The average height of the F-layer for the day time (afternoon) was 250 km. It was independent of the wave-length. It varied with the season of the year and the hours of the day. At night it was about 20 per cent less than during the day time.[55] The authors recorded that the early observers seemed to not have noticed that Appelton, Watt and Herd "system of aerial gave much stronger echoes owing presumably to stronger radiation in the upward direction."[56] After reading Mitra *et al.* article R.A. Watson Watt and L. Bainbridge-Bell from the Radio Research Station wrote that they are working in the direction to remove this defect.[57]

### *Solar Eclipse and the Ionization of the E- and F-layers*

In 1931, S. Chapman proposed that the E- and F-layers are due to the ionization which is caused by ultra-violet rays and neutral particles from the sun. To find out the amount of ionized particles, he suggested making the observations during a solar eclipse. Mitra's group applied this method and measured the ions content for three days. They found a slight variation in the F-layer in the morning time. However, their results were not conclusive, as two days later a similar effect was observed by them. The authors concluded that the ultra-violet light is at least one of the causes of the ionization of the E-layer, whereas corpuscular rays have little or no effect. Fundamentally, they reconfirmed the early results of the European scientists.[58]

### *Experimental Discovery of the D-layer*

In 1935, Mitra *et al.* stated that different authors had suggested the existence of D-layer but had not experimentally found its existence. They wrote that by using the pulse method, the echoes of radio waves returned from a height of ca. 55 km had been observed. Simultaneously, the measured height of the E-layer was 119 km.

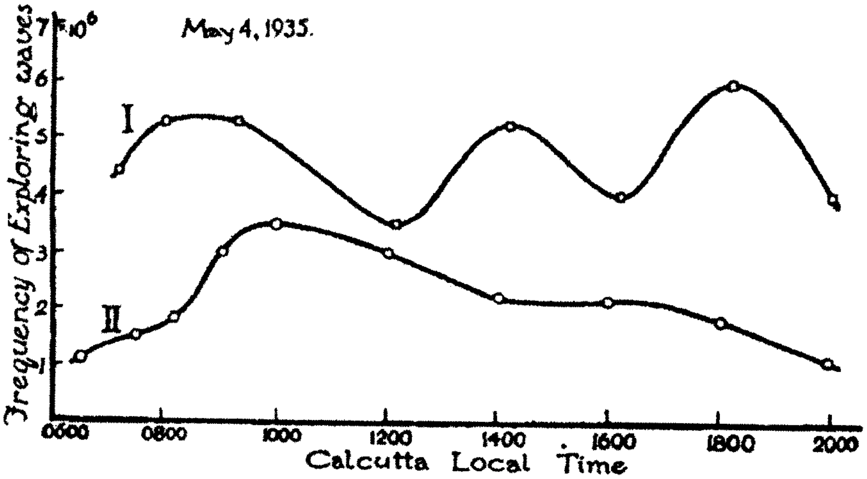


Fig. 5: Curve I is the graph of the penetrating frequencies of the E-layer; Curve II the echoes from the E-layer (Courtesy, "Nature" 135, 1935).

They wrote that: "The hypothesis of a diffuse E-layer boundary causing absorption is untenable because the virtual height of the E-layer as measured by us for a number of frequencies in the frequency band of (Fig, 5) has been found to be practically constant." Their arguments in favour of the D-layer were:

> "Without the intervention of such a region, the virtual height of the E-layer ought to rise gradually with the setting of the sun. Observations show, however, that the height has a tendency to decrease with the close of the day. This is easily explained due to the

> disappearance of the D-layer, which by its presence during the day, increases the virtual path of the wave. Again (Fig. 5) shows that Curve I, which is a graph of the penetration frequencies of the E-layer, has pronounced hourly variations. The feature of the curve is present almost every day during this part of the year–Curve II, which is a graph of the frequencies for which echoes begin to appear from the E layer, has no such pronounced hourly variations, but gradually rises and falls with the progress of the day. There being scarcely any correlation between the two curves, it follows that the agency responsible for the Curve I must be different from that for the Curve II. The other agency, according to our hypothesis, is the absorbing layer at a virtual height of 55 km."[59]

### *Determining the Electron Density of Nitrogen and Oxygen in the D- and $E_2$-regions*

Mitra *et al.* proceeded to observe the lower ionosphere, which is comprised of both the D- and $E_2$-layers. To do this, they studied the change of the refractive index and the absorption coefficient with respect to electron density at different collisional frequencies. They found that for certain values of electron density and collision frequencies, the refractive index increases rapidly. They concluded that the regions with the rapidly changing refractive index will be able to reflect the radio waves. They noticed that for nitrogen, an ionization maximum occurs at a height of 140 km, which corresponds to the height of the $E_2$-layer; whereas for oxygen, the ionization peak occurs at an elevation which corresponds to that of the D-layer (Fig. 6). They were of the opinion that the $E_2$- and D-layers are caused by the photo-ionization of nitrogen and oxygen respectively. They then concluded:

> "It is very likely that this latter ionization is enhanced during chromospheric eruptions and produces the radio fade-out effect. If this be so then one has to admit that the so-called D-region which causes absorption of radio waves is not a "tail" or a continuation of the E-region formed during daytime (as is sometimes supposed) but is a region of ionization maximum distinct from the E-region. As mentioned before the $E_1$-region is due to the second potential of $O_2$ while the D-region is due to its first ionization potential."[60]

### *Explaining the Appleton Magnetic Control Anomaly in the $F_2$-layer*

The F-layer consists of $F_1$-, which exists only during the daytime hours, and $F_2$-regions. Peak densities of these two regions are roughly 200 km for $F_1$- and 300 km for $F_2$-layer. E.V. Appelton reported that during WWII, in order to help the Allied Forces, ionospheric stations were instituted in the U.S.A., Australia, India, and New Zealand. This resulted in further studies of the E- and F-layers. He recorded:

> "A study of these data has disclosed the remarkable result that, although ionospheric events in the E- and $F_1$-layers are similarly reproduced at the same local time on the same day at all locations on a line of constant geographic latitude, the same is by no means the case for the $F_2$-layer. It has also been confirmed, as was suspected earlier, that under conditions of symmetrical solar illumination, an asymmetry of ionization exists for certain station on the same longitude and situated at equal latitudes north and south of the equator (Fig. 7)."[61]

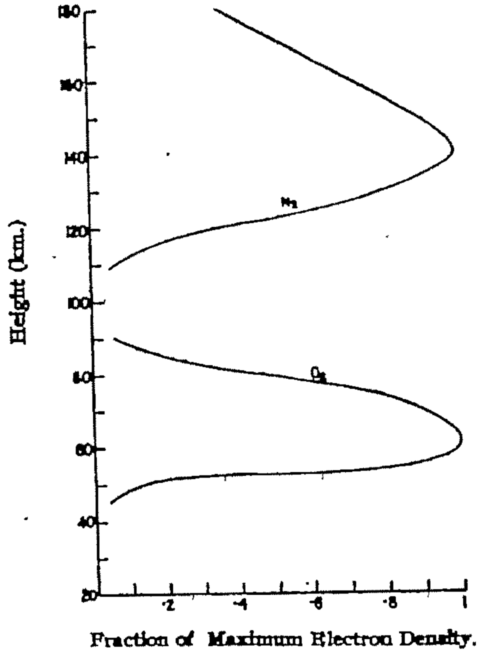


Fig. 6: "Fraction of maximum electron-density of oxygen and nitrogen for D- and $E_2$ layers respectively (Courtesy Ind. J. Phys. 12, 1938).

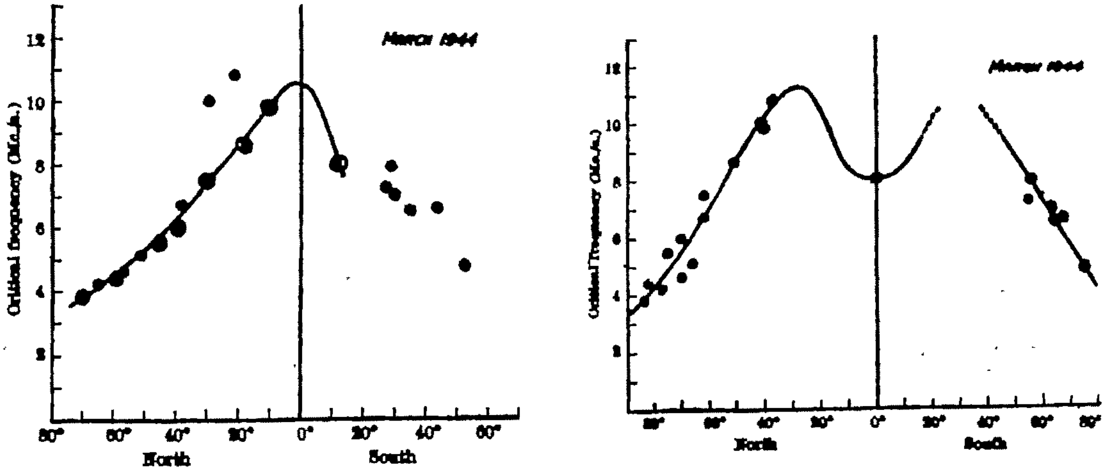


Fig. 7: Left: Variation of critical frequency with geographical latitude. Right: Magnetic dip (Courtesy "Nature" 157, 1946).

To explain the results, Mitra started with the argument that the effect is terrestrial in nature. He stated that:

"In the region high above the $F_2$-layer where fringes of the atmosphere might be supposed

> to begin, the collision frequency is very small, and the electrons and ions produced by solar ultra-violet rays have long free paths. They are thus free to spiral around the magnetic lines of force and, at the same time, are roughly guided by them, because, when formed by photon absorption, they will in general have velocity components along the lines of force. Now, at the magnetic equator the lines of force rise highest and slope north and south. The ions and electrons formed in the high atmosphere in the belt along the magnetic equation are therefore guided north and south and, when they come down to the lower levels, contribute to the ionization density of region $F_2$. The densities on either side of the magnetic equator are thus increased by this 'distilling' process which operated throughout the daylight hours."[62]

In 1955, D.F. Martyn "supplemented this [Mitra's] explanation by showing that, over the dip equator, there will be increased conductivity due to Hall effect and upwards movement of plasma by electro-dynamic lift and that this will be followed by diffusion down the lines of magnetic force."[63] Later, in 1965, R.J. Moffett and W.B. Hanson would demonstrate that Mitra's arguments were not enough to interpret the effect completely.[64] Even today, the phenomenon is not completely understood as the title of the article "The equatorial F-layer–Progress and puzzles" suggests. It refers to Mitra's work as follows: "...Mitra (...) suggested that the trough exists because plasma, produced by photoionization at great heights over the magnetic equator, diffuses downwards and outwards to the north and south, leaving depletion at the equator. Since the geomagnetic field lines passing through the F-layer crests (at about 15°±20° magnetic latitude) cross the equator at about 800±1000 km height, where the production rate ... is small, some other source of plasma seems necessary."[65] And further: "Martyn (1947) and Duncan (1960) envisaged that the plasma comes from lower levels in the $F_2$-layer; it is lifted to great heights by the eastward electric fields that exist in low latitudes by day, and then diffuses downward along field lines, as Mitra (1946) suggested."[66]

### *Meteoric Showers and Ionization of the E-layer*

A.M. Skellett, Bell Telephone Laboratories, advanced the theory that meteoric showers might cause ionization of the upper atmosphere. In order to prove the hypothesis, experimental observations were made by J.P. Schafer and W.M. Goodall. However, the results were not reliable as the magnetic storm effected their measurements. Mitra *et al.* showed that Leonid meteoric showers indeed play a role in the ionization of the E-layer. In order to exclude the magnetic effect, they argued that observatories in India have not reported special magnetic disturbances or solar activities.[67]

### *Explaining the Origin of the E-layer*

According to Indian historians, the first experimental evidence of the E-region of the ionosphere was obtained by Mitra and his co-workers in 1930; results were then published in "Nature."[68] Unfortunately, the authors did not provide the necessary reference rendering my efforts to find such an article unsuccessful. I suppose that the authors suggested that Mitra postulated the cause of the E-layer. For instance, in a letter to "Nature", Mitra wrote that his associate J.N. Bhar has detected maxima of ionization at 350 and 270 km, which are due to atomic oxygen and molecular nitrogen respectively. These elevations were identified with the $F_2$- and $F_1$-regions (Fig. 8).[69] Mitra stated that the E-layer is due to strong absorption resulting in photo-ionization of molecular oxygen.

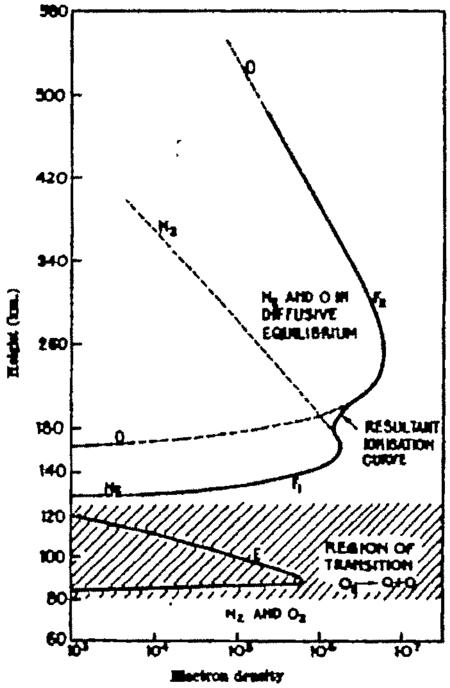


Fig. 8: The E-layer region due to the transition of oxygen molecule to oxygen atom (Courtesy "Nature" 142, 1938).

Today, it is known that the E-layer is caused by ionisation of molecular oxygen by far-ultraviolet and soft x-rays radiated from the sun.

### *Study of the Ozone and E-layer*

In the late 1870s, Walter Noel Hartley (1845-1913), Ireland, investigated the absorption spectrum of ozone and oxygen. In 1881, he came to the conclusion that ozone is a constituent of the atmosphere and its main concentration is located near the surface of the earth.[70] S. Chapman hypothesized that the concentration of ozone and atomic oxygen changes with the height of the atmosphere.[71] Mitra observed irregularities in the behaviour of the ionospheric E-layer at the times of sunset and sunrise. He attributed these fluctuations to the ozone layer and calculated the upper boundary of the absorbing layer to be at about 35 km (Fig. 9).[72]

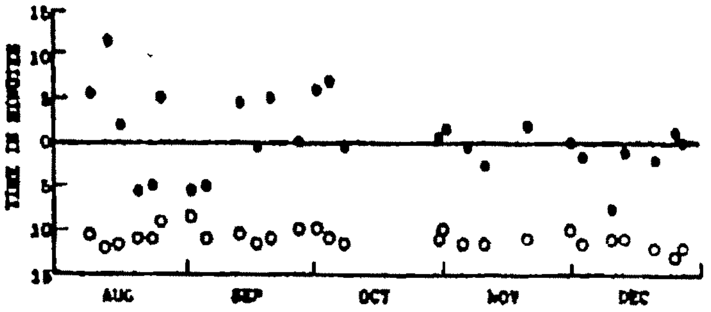


Fig. 9: Variation of ozone with time of the day. Dots: Beginning of the ionization of E-layer; Circle: Hours of sun rise. The ionization begins ca. 10 minutes after the sunrise. The line through zero is a reference line is at 35 km from the Earth surface (Courtesy Sci. Cult. 3, 1938).

Mitra wrote that it was well-known that the ionization results from ultra violet radiation and begins about an hour after the sun rises. According to him: "The dispersion of the dots about the zero line is due to the irregular daily variation of the height and the content of the ozone layer. In fact, the variation of the hour of the morning increase of the E-ionization may be used as an index of the variation of the ozone in the upper atmosphere."[73] In 1948, R. Penndorf found that much of Mitra's results were in agreement; however, "..., the height of the ozone layer in tropical latitudes may be expected to be the same as in middle latitudes, rather than being lower as proposed by Mitra."[74]

### *Distribution of Gases in the Upper Atmosphere*

In the 20th century, ionospheric scientists desired to understand the processes of ionization occurring in different layers. In 1938, Mitra and Rakshit numerically calculated the distribution of constituents of gases and their pressures in the upper atmosphere. They suggested that if a temperature increase with increasing height is assumed, the nitrogen and atomic oxygen will reach equilibrium state at heights above 350 km, whereas below 175 km they are completely mixed. If the constituents are supposed to be molecular nitrogen and oxygen, the aforementioned heights are 250 km and 175 km respectively. For constant temperatures, these heights are 175 km and 150 km. Also, the pressure for different constituents at different levels was calculated. Their results were higher than those of the previous observers. The authors wrote: "It is found that the calculated pressure at a height of 250 km (if the constituent gases are $N_2$ and $O_2$ and a high temperature assumed) agrees fairly well with that obtained from measurements of collisional frequency of electrons in the F-region by radio methods."[75] Mitra and A.K. Banerjee computed heights for atomic oxygen and nitrogen molecules 770 km. Above a height of 930 km, it was empirically found that there is a drastic reduction of collisions between atoms. Another conclusion, that the atmosphere rotates with the earth so long as there is appreciable collision between atoms, was made. They estimated molecular density at different levels of the fringe region (Fig. 10), that is, the region above the ionosphere.[76]

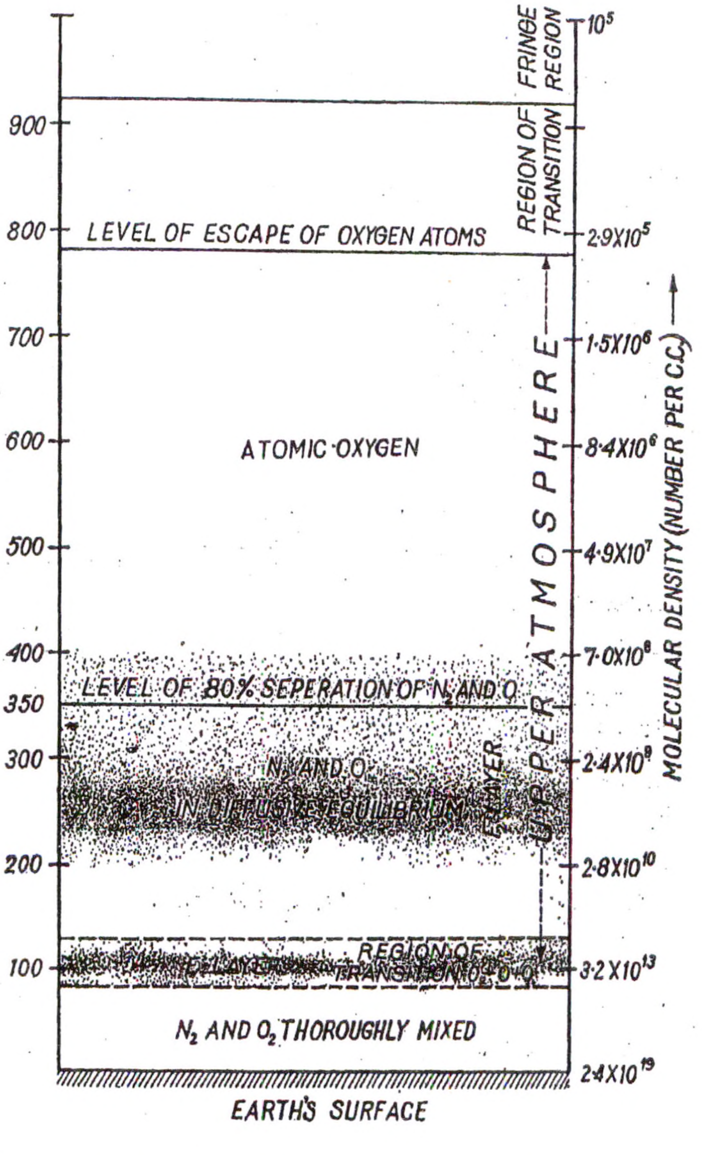


Fig. 10: The molecular density of different components, and relation between the kinematical viscosity and height (Courtesy Ind. J. Phys. 13, 1939).

The authors wrote that according to E.O. Hulburt's theory of aurorae and magnetic storm, the particles driven upwards by super-elastic collisions will be ionized in three hours.[77] Mitra *et al.* found that, in the case of oxygen, the time required should be several orders higher than that assumed by Hulburt.[78] And further:[79]

"i. Existence of super-elastic collisions between an excited (metastable) atom and a neutral particle extends the fringe region.

ii. Of the various metastable states of the constituent particles only those of oxygen atoms are capable of producing any effect by super-elastic collisions.

iii. It is found that roughly about $10^4$ atoms in the $^1S$ state and $10^6$ atoms in the $^1D$ state suffer collisions per second with other atoms.

iv. The atoms in the $^1S$ state can shoot a neutral oxygen atom to a height of about 14,000 km above earth's center while an atom in the $^1D$ state can shoot it to a height of about 9,500 km."

### *Thunderstorms and Sporadic Ionization $E_s$*

Mitra's interest in the subject dates back to the middle of 1930s. Under his guidance, J.N. Bhar and P. Syam, studied the effect of magnetic field and thunderstorms on the ionization of the Kennelly-Heaviside layer. They had observed a link between thunderstorms and an abnormal increase in E-region ionization, whereas, the influence of the magnetic disturbances on the ionization of the E-region was not very marked.[80] The sporadic E-layer ($E_s$) is a thin cloud of intense ionization; causes of this intense ionization were not known. In 1954, Mitra *et al.* studied the "Nor'westers" (special type of thunderstorms) in Bengal and proved that thunderstorms are one of the factors which influence the sporadic E ionization.[81]

### *F-region and Atomic Oxygen Collisions Process*

In the beginning of the 21st century, O. Zatsarinny and S.S. Tayal wrote: "Atomic oxygen is one of the most abundant elements in the universe and the accurate atomic data for electron-impact excitation of oxygen are of importance in the modelling of various astrophysical plasmas."[82]

In the beginning of the 1920s, the German, Carl Ramsauer (1879-1955), and the British, John Sealy Townsend (1868-1957), independently observed that contrary to the prediction of the classical theory of slowly moving electrons (with a certain amount of energy), the probability of collision between the electrons and noble gas atoms attains a minimum value. This process was named as either the Ramsauer effect, the Townsend effect, or the Ramsauer-Townsend effect.[83] In 1928, the British Douglas Rayner Hartree (1897–1958) developed a theory of an atom with a non-Coulomb central field.[84] With the help of the foregoing articles, in 1936, J.B. Fisk determined the total cross-section for elastic scattering of nitrogen, oxygen, and hydrogen gases.[85] Mitra's motivation to determine the cross-section for elastic scattering in oxygen atom was different, in that he wished to apply the knowledge to the field of ionosphere. Mitra *et al.* wrote that it was well-known that in the atmospheric regions beyond 150 km, atomic oxygen is dominant. Absorption of radio waves in the F-region is caused by collisions between electrons and atomic oxygen. In order to estimate the frequency of such a collision, it is essential to know the cross-section for elastic collision of atomic oxygen.[86] By applying the Hartree method, they produced a curve, which could be utilized for finding the frequencies in the F-layer. They suggested applying quantum mechanics for slow collision processes as it gives better results than the classical theory. The cross-section for oxygen atom for elastic scattering between the temperature ranges of 800 to 2000°K as calculated by them was 3.30-

$3.72 \times 10^{-14}$ $cm^2$.[87] Later, that is, in 1978 S.N. Ghosh and P.K. Sarkar showed that the discrepancy between the experimental and theoretical results in the F-region, which was observed in previous years, can be resolved by adopting the momentum transfer cross-section of atomic oxygen and slow electrons.[88]

### *The Monograph – "The Upper Atmosphere"*

How Mitra came to write a book on the upper atmosphere is answered in the "Preface" of the first edition of "The Upper Atmosphere." Mitra wrote that in August of 1935, he was invited by the National Institute of Sciences, India, to open a symposium on the ionosphere. His address on the "Present state of our knowledge of the ionosphere" was well appreciated by workers in different fields. During a visit to U.K., in 1936, M.N. Saha suggested him to write a book on the atmosphere. It is not clear when the manuscript was ready for publication. According to Ashesh Prasad Mitra (1927-2007), his teacher S.K. Mitra asked several publishers, but the replies were not encouraging.[89] Due to Saha's efforts, the first version of Mitra's book came out in 1947. It is not only the content which is important from historical point of view. The book shows "Mitra's style of working", namely, he preferred to be acknowledged than being a co-author. Help rendered to him by others was always recognized. In the present book, he acknowledged his colleagues and workers from his laboratory. A few of them to be mentioned are: J.N. Dhar–Reader in the Department of Radio Physics and Electronics; S.N. Ghosh–Imperial Chemical Industries Research Fellow; S.S. Baral–Senior Research Assistant; A.P. Mitra–Junior Research Assistant; A.K. Saha–Junior Research Assistant; R.B. Banerji–Government of Indian Research Scholar; M.K. Das–Research Assistant; Miss Mrinmoyee Ghosh–Ghose Research Scholar; R.K. Mitra– Junior Research Assistant and D.K. Bose–Ghose Research Scholar.[90] In the preface we also find that it was due to M.N. Saha–President of the Asiatic Society that the book was published by the Society.

In 1952, B.H.B. wrote review of the second edition. He appreciated Mitra's work as follows: "..., the book is, and will remain, the standard work in its field. It is indispensable to those actually engaged on subjects coming within its scope, if only for the remarkably extensive bibliography, which contains more than 800 references. Others will find it a stimulating, if not always infallible, guide to a rapidly advancing and expanding field of study."[91] "The Upper Atmosphere" was often cited or referred to by others.[92] In the beginning of the 21st century, an author wrote as follows: "Global change science began in India with the publication of the book "The Upper Atmosphere" by S.K. Mitra in 1947. He considered for the first time, the atmospheric environment as a whole–neutral and ionized– its thermal structure and distribution of constituents, its motions, the interaction of the solar radiation and the particles streams from the sun with these constituents."[93]

### *The New Phase of the Ionosphere Research and Mitra's Vision*

In 1960, Mitra was elected President of the National Institute of Sciences, India. His Presidential Address covered the "Upper atmosphere and space exploration with artificial satellites." In his long lecture, he referred to the work done by the American, Russian, and European scientists after 1955. Despite a monopoly on rocket technology by these three, Mitra was affirmative that the COSPAR (Committee on Space Research), established by the International Council of Scientific Unions will help the other countries to do research work. What about India? He stated that we have enthusiastic groups working on atmosphere, which most probably was referring to groups initiated by H.J. Bhabha, M.N. Saha, and Kalpathi Ramakrishna Ramanathan (1893–1984). He suggested: "If they [groups] can formulate the research problems clearly and can undertake the design and construction of the necessary instruments with the economy of space and weight as demanded, it may perhaps be possible for India to reserve, on behalf of such groups, space in satellites of other nations."[94]

Mitra's passion for atmospheric studies was life-long. Just six months before his death, he delivered the Seventh Meghnad Saha Memorial Lecture at the Saha Institute of Nuclear Physics, Calcutta. This lecture covered the topic of "Physics of the earth's outer space." When asked about his choice of subject matter, he replied that it reminded him of his many years of research work and also Saha, who was happy that several features of his ionization theory were confirmed after the V-2 rocket launch in 1946. About the latest development in India he stated: "...I may invite attention to the recent press announcement that a rocket research station-without outside collaboration is going to be established at Trivandrum under the auspices of the Atomic Energy Commission. The announcement is very gratifying to all those who are interested in upper atmosphere and space research in the county. This will, in fact, be the first step towards India's participation in space research."[95]

In the 1960s, work was continued under his guidance as indicated in an article written by M.K. Das Gupta and D. Basu on the "slowly varying component of solar radio emission."[96] In the 1960s, India founded its own satellite programme. The history of the development of India's ionosphere research after 1960s is well documented by A.P. Mitra.[97]

### From Heaven to Earth–A New Theory of Active Nitrogen

In 1857, the Geissler tube, or gas discharge tube, was invented by the German Heinrich Geissler (1814-1879). Its original purpose was to demonstrate the principle of electric glow discharge in gases. Later, it was observed that, after the charge was cut-off, a visibly whitish, shimmering cloud remained. This phenomenon came to be known as afterglow. From 1862 onwards the effect was attributed to either nitrogen or oxygen or oxygen and nitrogen, or water vapours.[98] Robert John Strutt (1875–1947) from the U.K., was of the opinion that the effect is entirely due to a "new form" of nitrogen, that is, an "active" modification of the pure element (later known as "active nitrogen").[99] R.J. Strutt also studied the spectrum of afterglow, and found the characteristic yellow, red, and green bands.[100] He demonstrated that the faint red bands–$\alpha$ are due to the true afterglow nitrogen; the $\beta$ and $\gamma$ groups appear only when gases combined with oxygen are present.[101]

In the past, though much experimental, as well as theoretical, work was carried out, there was still no satisfactory theoretical explanation.[102] This puzzle was eventually solved by S.K. Mitra.

### *Study of the Night Sky Luminescence and "The Ionic Theory of Active Nitrogen"*

During World War II, blackouts were common in big cities such as Calcutta. To take the advantage of the situation, Mitra asked his students, S.N. Ghosh and S.S. Baral (1919-1991), to observe the night airglow when these blackouts occurred. From the roof of his house, Ghosh made observations of night airglow emissions and diurnal intensity variations. Electron densities of the F-region were measured by S.S. Baral at the Wireless Laboratory of the Science College. They noticed that on some nights, the two variations appeared to follow a trend (Fig. 11). This supported the hypothesis that night glow emission could also be a product of ionization of atmospheric constituents and subsequent recombination.[103] In 1943, Mitra recorded that night sky light has lines and bands, which are either green or red. He pointed out that various thesis had been put forward to explain their origin, but were unsuccessful. He began with the argument that the F-layer of the ionosphere contains not only neutral nitrogen gas ($N_2$) and atomic-oxygen (O), but also their ions ($N_2^+$, $O^+$, $O^-$) and free electrons.[104]

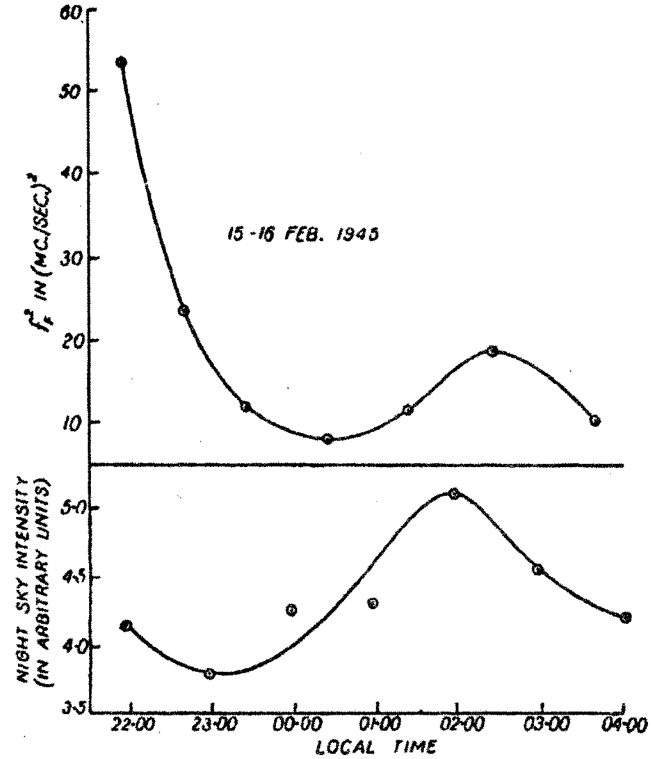


Fig. 11: Variation in the penetration frequency–Ionisation density in F-region and intensity of night sky with the time (Courtesy "Nature" 155, 1945).

According to Mitra's "ionic theory", the collisions take place between nitrogen ion ($N_2^+$), electron ($e$) and nitrogen gas molecules ($N_2$). Though there is a possibility of recombination of electrons and nitrogen ions; the theoretical probability for this is very low. In the process, nitrogen ions act as a major catalyst. The process which takes place is: $N_2^+ + e + N_2 \Rightarrow N_2$ (B-state) + $N_2$ (A-state). The neutral nitrogen molecule ($N_2$) on the left side acts as a third body. It absorbs the momentum and energy, which are released by the act of recombination. For emission spectrum of the three collision process, he gave the following expression: $N_2^+(X') + e + N_2 \Rightarrow N_2$ (B-state) + $N_2$ (A-state). According to this equation, when nitrogen molecules fall from B-state to A-state, radiation is emitted, which is observed as afterglow (Fig. 12).

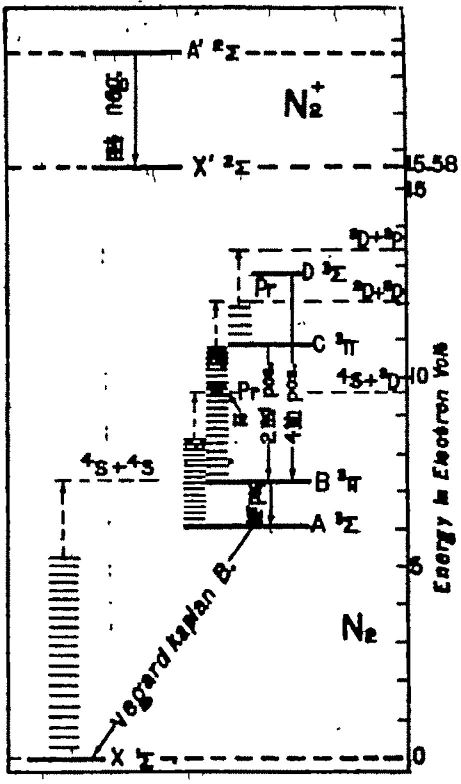


Fig. 12: A, B, C and D are the electronic states of the $N_2$ gas. "The afterglow takes place in the process of neutralization of nitrogen ion ($N_2^+(X')$) by an electron and a $N_2$ molecule. One of the molecules is raised to B-state and the other to the A-state. Due to the transition from B to A state the radiation is emitted" (Courtesy I.A.C.S., Active nitrogen–A new theory, 1945).

Mitra argued that it is evident that the ionization potential of nitrogen is 15.58 eV, which is released during the neutralization (Fig. 12). This energy can be absorbed by two molecules if one is raised to the A-state and another to the B-state. When the molecule in the A-state is in the lowest level (Energy 6.1 eV) the other molecule will take the remaining energy, that is, 9.48 eV, resulting in a jump to the vibrational level $v'=12$ (B-state with energy 9.75 eV). However, if the energy of the two molecules in two states is combined, it exceeds the required amount. Mitra justify that the particles possess kinetic energy, which has not been considered in the above calculation.

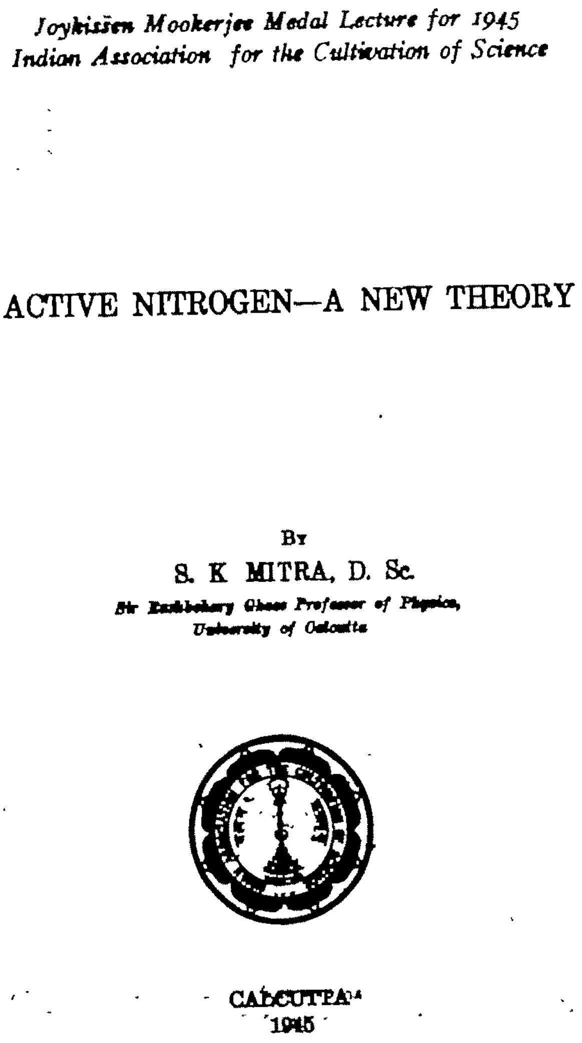
In his theory, Mitra suggested that A-state is highly meta-stable, thus the transition from this to the ground state (X) is a radiation-less process. The excited molecules transit from B-state to A-state producing the emitted observable bands of neutral nitrogen. For comparison of afterglow (in laboratory), night sky and aurora spectra Mitra gave the following table:[105]

| | $N_2$ | O |
|---|---|---|
| Afterglow | First positive (B⇒A) | |
| Night sky | First positive (B⇒A)<br>Vegard-Kaplan (A⇒X) | Forbidden lines<br>$^1S \Rightarrow {}^1D$ λ 5577 (green)<br>$^1D \Rightarrow {}^3P$ λ 6300 (red) |
| Aurora | First negative (A'⇒X')<br>First positive (B⇒A)<br>Second positive (faintly) (C⇒B) | Same as above |

Mitra noted that, as compared to the afterglow experiments in the laboratory, the actual pressure in the F-region is much lower. Consequently, the three body collision process is an extremely rare event originating from the excitation of nitrogen molecules and oxygen atoms. For such a process, Mitra gave the following equation: $N_2^+(X') + O^- = N_2$ (B-state) + O ($^1S$-state). He justified the Vegard-Kaplan bands in the night sky spectrum with the argument that, as the pressure is very low, the molecules in the A-state have the opportunity to revert back to the ground state (X) by emitting radiation. The theory that the aurora was caused by the bombardment of the fast charged particles from the sun was accepted. Its spectrum is "therefore comparable rather to the spectrum of the actual discharge in nitrogen than to that of the afterglow when the discharge stops", wrote Mitra.[106] So far the results of Lord Rayliegh were concerned, he, Mitra, noted:

> "Two of the experimental results of Rayleigh which have an important bearing on the present hypothesis are as follows: (1) The ion density as computed from observation of ionization current flowing between two electrodes is *less* than the number of photons emitted per unit volume from the glowing gas (in the initial stage). (2). Introduction of neutral $N_2$ increases the ionization current and also the intensity of the afterglow. These experiments require careful consideration as otherwise they can easily be interpreted as invalidating the proposed hypothesis."[107]

### *The Monograph: "Active Nitrogen–A New Theory"*



*Joykissen Mookerjee Medal Lecture for 1945*
*Indian Association for the Cultivation of Science*

ACTIVE NITROGEN—A NEW THEORY

By
S. K MITRA, D. Sc.
*Sir Rashbehary Ghose Professor of Physics,*
*University of Calcutta*

CALCUTTA
1945

Fig. 13: Facsimile of the title page of Mitra's monograph (Courtesy IACS, Kolkata)

As we have seen above, the fundamental idea of the theory was initially given in papers and lectures.[108] The details of the subject were published in a short monograph, which was based on the Joykissen Mookerjee Medal Lecture–IACS (Fig. 13). Mitra's had expressed that he was not aware that afterglow and ionization are connected with each other; early investigators agreed and declared that ions and electrons are not responsible for the effect. "Perhaps if I had known this I would not have ventured to propose the theory!" How he came to the idea of his new theory? In Mitra's words: "For some years past, I had been engaged in the study of upper ionization–the ionosphere. In connection with this study, I always felt that the faint glow in the night sky must, in some way, be related to the ionization in the high atmosphere, even as the ionization in a discharge tube is related to the glow in it."[109] In the monograph, Mitra summarized the success of his theory as follows:

> "The theory explains not only the broad features of the phenomena, such as the long life and the spectrum of the afterglow, but also such details as the maximum energy of spectral excitation, the negative temperature coefficient, the pressure effect, the decay rates (...), the power of producing phosphorescence, quicker fall of glow intensity than the ionization, and so forth. In particular, the phenomenon of ionization, which is side-tracked by all theorists, presents no difficulty as ionization in the afterglow is a part of the theory itself. No other theory offered so far succeeds in even touching the fringe of so many problems as are simply and naturally explained by the new theory. The nature of the active nitrogen, which had remained a mystery for nearly half a century, is no longer a mystery."[110]

### Reception of the New Theory by the Scientific Community

In "Nature", A.G. Gayon, U.K., while writing a review on Mitra's, book deemed the previous experimental work well documented. Gayon's praise was laced with criticism; from spectroscopy point of view. He stated that it did not refer to the work of M.L. Spealman and Worth Huff Rodebush (1887-1959), which had shown that the yellow-green air afterglow was due to reaction between nitric oxide and atomic oxygen, not between nitrogen peroxide. According to Mitra, it was caused by ozone.[111] The reviewer was in doubt: "whether it [theory] can explain all the facts, and it is unlikely to receive general acceptance."[112]

In 1948, L. Herman and R. Herman, while studying the emission spectrum of active nitrogen, referred to the monograph. They declared that Mitra's hypothesis is unable to explain all of the features of active nitrogen. They were of the opinion that strong emission of the first negative system is due to the recombination of the doubly ionized nitrogen ions ($N_2^{++}$) and electrons.[113] Mitra countered that the authors have missed one of the most important points, this is, his theory was developed for the long-lived Lewis-Rayleigh afterglow, and not for the short-lived Kaplan afterglow, the latter being quite a distinct phenomenon.[114] In the same year, that is 1948, Joseph Kaplan from U.S.A. referring to Mitra's article in "Science and Culture"[115] stated that Mitra's three-body collision equation for the Lewis-Rayleigh afterglow of nitrogen cannot account for the spectrum of the auroral afterglow. For the process, he proposed the following expression: $N_2^+ + e = N' + N''$ (the products being nitrogen atoms in metastable states), which is comprised of collisions of the second kind involving slow moving electrons and metastable atoms.[116] Mitra rebutted:

> "It is stressed that, contrary to Kaplan's view, the strengthening of the Vegard-Kaplan bands and of the first positive bands originating in $v' = 11$ in the later stage of the auroral afterglow, does not really contradict the reaction proposed. These observations merely show that factors not present in the Lewis-Rayleigh afterglow are operative in the auroral afterglows. ....In conclusion, it is stressed that the findings of Kaplan that $N_2^+(X')$ ions

> persist in the auroral afterglow throughout its entire duration and also that the alternative reactions proposed by him start with these ions support my hypothesis that active nitrogen is nitrogen ions in the $N_2^+(X')$ state."[117]

The ultimate experiment to disprove Mitra's "ionic theory" was performed by James M. Benson, U.S.A. He noted:

> "Ionization in a stream of active nitrogen is shown to be accidental rather than essential to the production of the Lewis-Rayleigh afterglow. Microwave measurements of the free electron density in a stream of active nitrogen indicated one free electron for each 2.3 x $10^8$ molecules in a stream. Contrary to Mitra's theory, probes in the stream were found to respond to carriers of negative ions rather than positive ions. Space discharges in an expanding stream of active nitrogen are attributed to free electrons moving with the stream."[118]

***"Metastable Atomic Theory of Active Nitrogen"***

Mitra realized the need for improvement of his dated theory and formulated a new theory. According to it, nitrogen ions and electrons were parent bodies of active nitrogen. By dissociation ($N_2^+ + e \rightarrow$ N (excited) + N (excited)), the active nitrogen atoms in the ground states ($^4S$), and a small part in the metastable states ($^2D$ and $^2P$) are produced (Fig. 14). With these suppositions he explained the two main features of the active nitrogen, that is, the long-duration of afterglow and the invariable presence of ionization in the glowing gas. He argued: "The long life of the afterglow is explained as resulting from the fact that the wall recombination of the N atoms is prevented by the formation of an adsorbed layer of $N_2$ molecules on the wall surface. ...."[119] An additional characteristic is the invariable presence of ionization due to recombination of metastable atoms $N(^2D) + N(^2P) \rightarrow N_2^+ + e$. Mitra applied the "Metastable atomic theory" to explain the Lewis-Rayleigh afterglow spectrum, presence of ionization in the glow, the negative temperature coefficient, and the dark modification. He recommended a thorough spectroscopic examination of the predissociation of $N_2$ (B-state) molecule, as there was difference of opinion about its exact nature.[120]

In 1958, K.R. Jennings and J.W. Linnett, supporters of Mitra's book, wrote on active nitrogen. They praised Mitra's monograph as an excellent review of experimental work with many references to the original papers. The authors reexamined the literature from the previous ten years and came to the conclusion that as nitrogen has three electrons in the outer shell, it can form chemical bonds with other atoms, which leads to different energy states.[121] A year later a pink colored afterglow was observed by G.E. Beale and H.P. Broida. They ascribed the effect to some highly energetic species other than nitrogen atoms.[122] In 1970, R. Brown and C.A. Winkler, in a review article, showed the possibilities of active nitrogen reactions with a large number of elements which encompassed organic- and inorganic compounds. They concluded that "although nitrogen atoms are responsible for many of the reactions of active nitrogen, electronically excited molecules also play a role."[123] This exposed the difficulty of explaining the experimental results. Keeping their investigations limited to the Lewis-Rayleigh afterglow, they stated that the earlier theories failed, partially due to the conflicting experimental evidence.[124] In the same year, that is, 1970 in the "Reports on Progress in Physics" J. Anketell and R.W. Nicholls declared the work of Mitra, Jennings and Linnett, and Wright and Winkler as authoritative on the subject of active nitrogen. They demonstrated that to understand the glow effect and its spectroscopic interpretation "collision-induced vibrational relaxation, collision-induced electronic quenching, and a number of other collision-induced radiation less transitions are very important."[125]

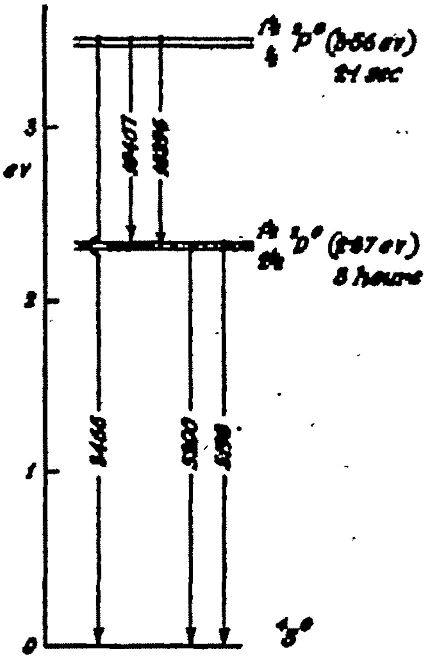


Fig. 14: A nitrogen atom and its energy levels in metastable states. The active nitrogen, that is, atoms in the ground and metastable state are produced by dissociative recombination of $N_2^+$ ions and electrons (Courtesy Phys. Rev. 90, 1953).

Mitra's work was an integrated part of the scientific community abroad. Not surprisingly, he was invited to send proposals for the Nobel Prize and was nominated for the Fellowship of the Royal Society of London. Further details are given below.

### S.K. Mitra as Nobel Prize Nominator

The record of the Nobel Committee of date January 1, 1930, shows that from the University of Calcutta, S.K. Mitra–Khaira Professor of Physics and D.M. Bose–Ghosh Professor of Physics, sent a joint proposal to the Nobel Committee. It reads : "We beg to propose the name of Prof. Megnad Saha D.Sc., F.R.S. of the University of Allahabad, India, for the Nobel Prize for Physics for 1930. We append herewith a statement of the important contributions to Physics made by him during the last few years and which in our opinion entitles him to the award of a Nobel Prize."[126] They nominated Saha for his work on "The Theory of Thermal ionisation" and "Selective Radiation Pressure."[127]

For the year 1930, the Committee prepared a special report in the form of a 5 page analysis of Saha's work, written by Vilhelm Carlheim-Gyllenskōld (1859-1934). He agreed that Saha's work gave physical meaning to the data collected on stellar spectra by Harvard astronomers. The expert and the Committee were of the opinion that his work on selective radiation pressure was by no means of the same importance as the thermal ionization theory.[128] The Committee stated: "With all recognition for the value of Saha's achievements, the Committee find itself not in the position to recommend him for the reception of the Nobel Prize for Physics."[129]

Saha was again nominated by Mitra on Nov. 18, 1938. Mitra begun with the statement that he had carefully studied the previous awards as well as their rules and regulations. He proposed Saha "for his great work on 'Thermal Ionisation of Gases, and its application to Physics of the Sun, the Stars, and to the problems of the Terrestrial Atmosphere, and to Thermionics.'"[130] Mitra wrote that the papers authored by Saha in 1920-1921 are so well-known that it is superfluous to give reference. So far, the application of Saha's endeavours in the field of thermionics and thermal conductivity of flames was concerned, Mitra stated: "Dr. I. Langmuir, and his co-workers, and several others (...) found that Saha's theory of thermal ionisation of elements can explain the anomalies in the emission of electrons from incandescent metallic filaments in the presence of vapours of alkalies and other elements."[131]

Mitra, being an expert of the upper atmosphere of the earth, was well informed about the work of Saha as well as other scientists. In favour of Saha's theory, he argued: "..., the most fundamental problem, viz., formation of electronic layers (E and F) can be explained only with the aid of Saha's theory. This was shown in a general way by Prof. A. Pannekoek in 1926, and by Prof. S. Chapman in 1931. Recently Saha himself has worked out a brilliant synthesis of the two theories and has further explained successfully the formation of the different layers."[132] After showing the importance of Saha's work he closed his letter as follows:

> "From the foregoing short account of Saha's work, it will be seen that as in the case of many other great works of a theoretical nature in Physics, the value of his contribution has only been slowly recognised. But the work has stood the test of the last eighteen years, and the opinions of the experts, some of which are quoted above, demonstrate clearly that the work possesses the preeminent excellence foreseen in the will of Robert [presumably, Alfred] Nobel." [133]

According to the records of the Nobel Committee, no report exists on Saha's work for the year 1939. Obviously, the Committee did not deem his work worthy to evaluate again.

In 1954, Mitra once again received an invitation from the Nobel Committee. In a long letter, on November 15, 1954, Mitra first criticised the attitude of the Nobel Committee as follows:

> "I find it rather strange that in course of 55 years of its existence the Nobel Committee has not seen its way to recognize "Astrophysics" as one of the subjects of its award under Physics. "Astrophysics" is not merely physics applied to understand physical conditions on the sun and the stars, and in interstellar space. It has, on the other hand, very often

> suggested problems which have greatly enriched Physics, ....It is high time that Astrophysics is selected as one of the subjects for a award in Physics, and I can think of no living astrophysicist who deserves this award more than Prof. M.N. Saha."

Mitra quoted from A.S. Eddington's article from the "Encyclopaedia Britannica", in which Saha's equation was listed as one of the twelve great discoveries. In the end Mitra wrote that Saha was aware that his equation is valid only under equilibrium conditions. In the 1930s he improved the theory. Consequently: "These studies led him to predict in 1938 that if the spectrum of the sun could be observed above the ozone layer, the Lymen lines of Hydrogen would be obtained in emission. These predictions have been brilliantly confirmed by the rocket experiments carried out since 1950."

After sending his nomination, he asked for support from the Nobel Laureates from the U.S.A. and U.K. For example, Harold Clayton Urey (1893–1981), University of Chicago, thanked Mitra for his communication in regards to Saha. He committed to include Saha's name in the nomination for that particular year.[134] Similarly, a letter from Patrick Blackett (1897-1974) also shows that Mitra requested him to consider Saha. His answer was not promising. He was of the opinion that Saha's work belongs in the field of Astronomy, for which there is no Nobel Prize. However, he suggested Mitra that there would be no harm if there was more Indian support for Saha's case.[135] As the record of the Nobel Committee shows, neither H.C. Urey nor P.A.M. Blackett nominated Saha. As in previous years, the Nobel Committee did not prepare a report.[136]

### S.K. Mitra—Fellowship of the Royal Society London

The documents of the Royal Society show that the first time, on Nov. 27, 1944, Mitra was nominated for the Fellowship of the Royal Society. His "Proposer" and "Seconder" were M.N. Saha and E.V. Appelton respectively. Eight more scientists signed the certificate from personal knowledge. Mitra's proposal was based on the following scientific achievements: "Founder of an active school of ionospheric research in India in 1934 since when he and his pupils have made substantial contributions to both the theory and practice of the subject. Discovered the existence of low-lying layer of ionisation in 1935, and has by his theories, greatly advanced our knowledge of ionospheric stratifications, excitation of the night-sky spectrum, and of the nature of active nitrogen." So far his social status as a scientist was concerned, he was quoted as "Chairman of the Radio Research Committee of the Board of Scientific and Industrial Research, Govt. of India; Editor, "Science and Culture"; Secretary Indian Science Congress Association."

In spite of support by prominent and influential persons like Appelton, Chapman and A.V. Hill; Mitra was not elected in 1945. One of the primary reasons seems to be that in the mid-1940s, many Indian candidates were nominated, for instance, D.S. Kothari, M.O.P. Iyengar, S. Bhagavantam, R.S. Krishnan and T.R. Seshadri.[137] Over the following years, Mitra's certificate for the Fellowship of the Royal Society was suspended, until it lapsed in 1949. The next time Mitra was proposed "From Personal Knowledge" by M.N. Saha, H.S.W. Massey, E.V. Appleton, H.S. Jones, J.B.S. Haldane, A.V. Hill and S. Chapman. They quoted his qualification as follows:

> "Distinguished for his researches on the Ionosphere, on airglow and on the nature of active nitrogen. Founder and leader of an active school of Ionospheric research in India. Was instrumental in establishing the Radio Research Committee (of the Council of Scientific and Industrial Research, Government of India), of which he was the first Chairman. General President, Indian Science Congress Association (1954-1955). His comprehensive treatise on the "Upper Atmosphere" has received world-wide recognition and is the first book of its kind. It is in many respects an original contribution and has stimulated researches on the high regions of the atmosphere. Author of a large number of papers by himself and his pupils, of whom he was the inspirer."[138]

In 1958, both Mitra and S.N. Bose were elected as Fellows of the Royal Society of London. During that same year, Mitra was elected as the President of the Indian National Science Academy. He became the Corresponding Member of the International Academy of Astronautics in 1962; also the president of India declared him "Padmabhushan" and "National Research Professor." His legacy remains in India through those who worked with Mitra and to the countless inspired and influenced scientists.

**Conclusions**

Mitra's life and scientific work is a fascinating story of international relations, colonial history, and development of physics in India. From the foregoing we conclude:

- The lesson to be learnt from S.K. Mitra's life is that, in spite of poor support from the Government, he and his associates "experimentally discovered the D-layer", gave plausible "explanation of the origin of E-layer", "calculated the cross-section of atomic oxygen for elastic collision with electrons", and observed different aspects of D-, E- and F-layers. The publication of their papers in international journals such as "Nature", "Physical Review", and "Philosophical Magazine" leaves no doubt about the quality of their work. Mitra's life history shows that success in science is much more than possessing expensive imported scientific instruments.
- Mitra's biography shows the importance of living and studying in a foreign country, and working with renowned scientists. Visits to international institutions and laboratories can form connections which lead to a new field of research in visitors' home country. However, the "physical transport" of ideas, has its own problems. The lack of infrastructure and financial support might cause difficulty to realize the plans.
- In the U.S.A. and U.K., the regimes realized the importance of wireless and ionospheric sciences as "tools" with their applications in war. The scientists from these countries were financially supported either by the Governments or industry. In India, the situation was entirely different; apart from lack of industry, there was seemingly no relation between the Colonial regime and its "subordinate" scientists. Chances to get financial

backing were negligible if not non-existent. It occurs when a "Colonial Government" shows less interest in a particular research field. This explains the slow development of the scientific field initiated by Mitra. The British scientists tried to help the Indian men of science. At the first glance, it seems generous. However, E.V. Eppelton's article shows that behind this support sometimes, there were political motives, such as the collection of data, which was useful for military purposes.

The first time the phenomenon of afterglow was observed was in the beginning of the 1860s. In spite of being unaware of the past theories and experimental work, Mitra successfully gave its explanation in the 1940s. This shows that sometimes a man not from the same field may come with new ideas as he is not influenced by the dogmas of the community.

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# A Tale of Two Giants: M.N. Saha & H.N. Russell

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## 1

Were it said that Russell to Saha was as Einstein to Bose, no better parallels could be drawn. Were it *not* said that without Saha, Russell could not be what we largely know him for, it would be compromising truth.

The relation between these two giants is exceedingly interesting. On the one hand, it is complex because of the inevitable undercurrent of a competition. On the other, it exemplifies the height a symbiosis between two great minds, holding each other in high esteem, can attain.

Henry Norris Russell was sixteen years older to Meghnad Saha and outlived him by a year. They were both October-born (Russell, Oct 25, 1877; Saha, October 16, 1893) and they both died in February (Russell, February 18, 1957; Saha, February 16, 1956). Both received their education at best of places, Russell at Princeton, Saha at Presidency College, Kolkata. By profession, one was an astronomer, and the other a physicist. And that made a telling difference.

## 2

Russell and Saha knew of each other's work long before they met. Russell had the reputation for his stellar classification (Hertzsprung (1908)-Russell (1913) Diagram) as also his theory of stellar evolution when Saha was only graduating. In fact, Saha's fourth paper, revised at Alfred Fowler's laboratory in London in 1919-20, began with a reference to a 1914 paper by Russell. Russell, while visiting England in the spring of 1921 to receive the Royal Astronomical Society's Gold Medal, had looked for Saha, but then Saha had already left England. When their meeting took place in the States in 1936, very little was left for Saha to do. By then, Russell had harnessed the potential of Saha's work almost to the full. With two great observatories in the States—Mt Wilson and the Princeton University to his access, Russell did in in three years. The curious thing is, with that he ensured for Saha a permanent place in the annals of astrophysics.

## 3

January 1921. Saha left Alfred Fowler's laboratory to join Walther Nernst in Berlin. He was after getting his Ionization Formula experimentally tested. Ionized cesium had not posed any problem for him, but for other elements he needed a much hotter oven, which, they said, was with Nernst. By July, however, Saha had realised, even Nernst's was no good, the temperature range he wished to cover was not there. Further on the lookout, he spoke with Herbert Hall Turner in Oxford while attending the British Empire Universities Conference. Turner advised him to try his luck at the Mount Wilson Solar Observatory in the States. This is how it all began.

## 4

On July 9, 1921, Saha wrote to the Director George Ellery Hale at Mt Wilson, telling him what he had already done and what more could be explored. He wrote, (1) In *Ionization in the Solar Chromosphere,* Phil. Mag. Oct. 1920 (paper I), he had explained the exclusive occurrence of the lines of $Ca^+$, $Sr^+$, $Ba^+$ in the upper chromosphere [1], and the disappearance of the lines of Ca, Sr, Ba from this region. He was yet to explain the occurrence of lines of $Ti^+$, $Fe^+$, $Mn^+$, $Va^+$ etc. which required a knowledge of the ionization potentials of these elements. He suggested that an attempt might be made to obtain the 1S-terms [2] of these elements from spectroscopic data after the manner of Fowler and Paschen, and investigate the enhanced lines [3] of these elements (e.g., $\lambda = 5018$, 4924 A in the case of $Fe^+$). (2) On p. 815 of *Elements in the Sun,* Phil. Mag. Dec. 1920 (paper II), he had explained the apparent absence of Rb and Cs as being due to the fact that they are completely ionized in the Sun, and the lines of $Rb^+$ and $Cs^+$, unlike those of $Sr^+$ and $Ba^+$, lie too far in the ultraviolet. The resonance lines [4] of K, Nb, Cs all lie in the infrared and should come out in the spot [5] spectrum, if the investigation was to be carried out to $\lambda = 9000$ A just as Maggers had done for the ordinary spectrum. These points might be tested in the Mount Wilson Observatory. On p. 824 he has said, the spectra of Faculae [6] might be similar to the spectra of F-class [7] of stars. (3) In the paper *On the Physical Theory of Stellar Spectra*, Proc. Roy. Soc. May 1921 (paper IV), he has considered the varying intensity of the characteristic lines of Ca, $Ca^+$, Mg, $Mg^+$, H, He, $He^+$ Sr and $Sr^+$. But there was a large number of other stellar lines which might be investigated from the same standpoint, *e.g.*, Mn (4030 group), $Mn^+$ (3442 group and 4344.4 group), Fe (4583 group), $Fe^+$ (4255, 5016 etc), Ti, $Ti^+$, C, $C^+$, Si, $Si^+$, O, $O^+$, N, $N^+$ etc. In his paper entitled *On the Temperature-Radiation of Gases*, Phil. Mag. Feb. 1921 (paper III), he had discussed some of King's experimental results in connection with spectroscopy of heated gases. Later Russell would refer to it as laboratory end of research.

On 29 July, Saha hastened to send Russell reprints of his papers I and II and asked for some of his. He also wished to be put on his mailing list.

## 5

It was not in Hale's nature to write a reply, but he had the goodness to forward the letter to Russell. Having graduated from Princeton in Astronomy and earned a Ph.D. under Charles A. Young, Russell was now a Professor of Astronomy there. That January he had also been appointed a Visiting Research Associate at the Mt Wilson. Mt Wilson had always held a great attraction for him because two of his collaborators and finest experimentalists—William Sydney Adams and Arthur Scott King were there. Besides, Mt Wilson had a rich spectral archive.

As early as 17 December 1920, Russell had written to Adams, "Have you read a paper by

Meghnad Saha, in the last Phil. Mag. on Ionization in the Chromosphere (paper I)? I found it extremely suggestive; and I believe that within a few years we may utilize knowledge of ionization potentials, and so on, to obtain numerical determination of stellar temperature from spectroscopic data–or at least of relations between temperature and pressure. Saha's conclusion that low pressure and density are extremely favorable to double ionization and the appearance of enhanced lines is very interesting in connection with the remark which I remember in a letter of yours years ago, to the effect that the absolute magnitude lines for giant stars are all enhanced lines. At equal temperatures, the low density of the giant stars should directly favor the appearance of such lines". He went on, "Saha's calculation about the dissociation of hydrogen seems to solve a problem that always puzzled me, namely why do not we get the secondary spectrum [8] of hydrogen in astrophysical spectra? We calculate that dissociation should be complete except at considerable pressure (and) temperature [9] below 4000. At 3000, however, there should be a good bit of molecular hydrogen if the pressure was high. Now the familiar hydrogen lines are almost absent in the dwarf M stars, though fairly strong in giants of the same type–which led me to suggest that careful study of the spectra of dwarf M's, to see whether the secondary hydrogen spectra can be found, might well (be) worthwhile. You have the best existing spectra of such stars. Might it not (be) an amusing thing to try?"

Russell was vacationing in Clark's Island when Saha's letters arrived. Meanwhile, he had published an article in *Scientific American* of July 2, 1921, emphasizing the importance of Saha's work. Not only that, basing on it he had also fully chalked out his own course of action He had been working along many fronts, but was a bit unfocused; between 1914 and 1919 he had, to his credit, 26 astronomical papers in 15 distinct areas. But when he read Saha's paper I, Russell began to focus. As DeVorkin observes, "Russell's personal ambition was to take a lead role in exploiting the new explanatory framework created by Saha. Just as Bohr theory of Kirchhoff's laws has provided new sets of tools with which both the nature of atom and composition and constitution of the stars could be studied, Saha's thermal ionization equation demonstrated that much of the work that had remained isolated at Hale's laboratory could now be combined. Hale's spectroscopic staff, pushed now by Russell, started to move in this new direction." Saha simply spearheaded him to that.

## 6

On July 2, 1921, Russell had also sent out to *Publication of the Astronomical Society of the Pacific* (PASP) another paper entitled *Rubidium in the Sun.* The opening paragraph of this paper read, "Dr M.N. Saha [Phil Mag **40** (1920) 814] predicts that the principal lines [10] of rubidium, which are invisible in the solar spectrum, should appear faintly in the spectra of sun-spots. The search for them is made an easy matter by the recent publication of extensive and accurate tables of wave-lengths in the extreme red, both in the solar spectrum and in the arc, and by the existence at Mount Wilson of a fine set of plates of the spot-spectrum extending to $\lambda = 8200$, taken by Mr Brackett with the 150-foot tower telescope and 75-foot spectrograph, in the first order, and with Nicol prism and compound quarter-wave plate". He continued, "On examination of these plates rather conspicuous spot-lines were seen very near the known positions of both lines of the principal pair of rubidium. These lines are strictly confined to the spot, are rather diffuse, show a strong Zeeman effect, and resemble in all particulars the well-known lithium [$1s^22s^1$, IP 5.392] line at $\lambda$ = 6708....... The presence of rubidium in the Sun appears to be established".

The next day Russell wrote Saha a reply. While acknowledging the two letters, he said, he had long wished to write to thank him for the reprints of his first two papers and to tell him of the very high opinion which he held of his work. In his opinion, Saha had made a great contribution to astrophysics which was of the highest value and importance and opened great opportunities for future advance. He assured Saha that his predictions about the lines of alkali metals in the sun-spot spectrum were completely verified. "Rubidium is present". The lines of the alkaline earths also behaved in a manner which agreed very remarkably with Saha's theory–except that the spectroscopic evidence indicated that *barium was a good deal more easily ionized than sodium*. By comparison of the behaviour of the lines of other elements he found data strongly supporting Saha's conclusion that the ionization potential of Ti, Fe, Co, Ni, Ce lay between 6 and 9 volts. However, he was curious to know how Saha got these estimates. Russell added, "Dr. Hale, Dr. Adam, Dr. St. John and other members of the staff here were greatly interested in the various applications of the ionization theory. They had already discussed the desirability of work along all the lines suggested in his letter and it was probable that a great deal would be done, either at Mt. Wilson or at the CalTech, which was to develop a great physical laboratory under the direction of Dr. R.A. Millikan". He assured, at Mt Wilson they would investigate cesium as soon as proper photographs of the spot spectrum near $\lambda$ = 6500 were available. Russell also enclosed for Saha's perusal a carbon copy of the notes prepared for the said PASP. He added that he had noted several points on which Saha's theory could be fruitfully modified, for example, by including effects of ionization of several elements rather than one—as Saha had assumed for simplicity.

5 August 1921. Russell addressed a gathering of the Pacific Division of the American Association for Advancement of Science in Berkeley, elaborating in glowing terms how Saha's Ionization Theory would help science possess a "rational theory of stellar spectra, and, at the same time, much additional knowledge concerning the constitution of atoms". Little did he know, Saha, while revising his fourth paper [IV. *On a Physical Theory of Stellar Spectra*, Proc. Roy. Soc. Lond., May 1921] at Fowler's laboratory had already dealt with the first part of what Russell foresaw. He was yet to see Saha's paper IV. In fact, in his reply he asked Saha for a copy of it.

When Russell in the States was busy exploiting Saha's work, Edward Milne and Ralph Fowler at Cambridge were embarking on several projects based on Saha's Ionization Theory. Like Russell, Milne had also written popular articles on it. But the queer thing is that, almost everywhere in Europe they would refer to it as Saha-Eggert-Lindemann theory. However, with Russell's persistent use of Saha's name alone, the other names eventually dropped out.

In October 1921 Saha decided to return to Kolkata. Before leaving the continent, he wrote Russell a few lines in reply from Paris (11 October 1921) appreciating his kind words. On the many questions Russell had raised, Saha said, he would revert to him from Kolkata. He was sailing on the 20th.

## 7

Let us now take a quick look at what else Russell was doing after he read Saha's paper I. On October 14, 1921, he wrote to Arthur Stanley Eddington, "My two months at Mt Wilson were even better than I expected. I got very much interested in application of Saha's Theory of Ionization and have a paper in press, confirming all the predictions and adding some new material.... Please give my congratulations to Milne on his admirable presentation of the Ionization Theory in the *Observatory*". On November 8, 1921, he wrote to WS Adams, "I am much interested to hear of St John's work on the faculae. It is really what one should have expected, but Saha got ahead of us, as on several other occasions. Have you ever tried, by the way, such as we use on the stars, to get its spectral type? It would illuminate things considerably if we could describe the Sun as a G0 star [7] with F8 faculae and N2 spots". On November 9, Arthur King added a postscript in his letter to Russell, saying, "I want to look closer into the matter of lines appearing in absorption before emission. Saha may be right as to the initial appearance. My experiment shows that with a well developed spectrum the emission and absorption for the same thing are very nearly identical......". A week later (November 16, 1921) Russell replied, "I am very glad to hear that you have confirmed the effect of strontium $\lambda$ = 4078 and 4216. Another element of great interest is barium ([Xe]$6s^2$, IP 5.212). You remember that I found that barium in the Sun appears to be much highly ionized than Sodium ([Ne]$3s^1$, IP 5.139], although on Saha's theory they should be equally ionized. Experiment in the furnace with barium alone, barium and potassium ([Ar]$4s^1$, IP 4.341), and barium and sodium should show whether the peculiar behaviour is exhibited also in the laboratory. The critical lines are $\lambda$ = 4554, 4934 as compared with $\lambda$ = 5536".

Between October 20 to December 2, there was some correspondence between Russell and Samuel A. Mitchell of Leander McCormick Observatory, Virginia on something Saha claimed in respect of coronal [1] temperature, with which they did not agree. Sam wrote to Henry, "Apparently Saha is not very well up on matters of Astronomical interest, and being a physicist we could not expect him to be. His values of 7500K for the Sun was very surprising".

## 8

Russell had anticipated two things. One, that mixing has an effect on ionization in the main, for he had seen, even a trace of Cs (IP 3.894) suppresses the H ($\lambda$3968) and K ($\lambda$3933) lines [3] of $Ca^+$ (IP of Ca is 6.113, higher than that of Cs), and two, that barium was a different story. Having two electrons in the outer shell, it ought to be more ionized than sodium, which has only one. It was impossible for anybody in 1921 to guess the why.

Curiously enough, in November 1923 Russell would solve the problem in his own way, and thereby, stop short of making a great discovery, the credit of which rightfully goes to Pauli in two years. We shall come back to it later.

### 9

In the next two letters written from Kolkata, Saha, though initially querying (December 7, 1921) Russell's calculations, finally agreed (April 26, 1922) that mixing does indeed modify ionization in the main. To the question how he got the ionization potentials, Saha wrote, either from the published tables or by simply guessing. After getting to know, from this letter, of Catalan's work on Mn ([Ar]$3d^5 4s^2$, IP 7.435] at Fowler's laboratory, Russell thanked Saha (January 17, 1922) profusely but firmly maintained that his own calculations on mixing of elements were all correct. The following day he rushed a note to Alfred Fowler with a request to pass on to him the results of Catalan. He wrote, he was just going out to Mt Wilson for his second term of duty there, and was planning to work with Adams on the further interpretation of stellar spectra on the basis of ionization theory. It would be exceedingly valuable to them to know more about Mr. Catalan's results–the more the better.

### 10

While his work generated a spate of activity in the West, Saha was languishing at Kolkata for want of facilities. On 26 April, 1922 he wrote to Russell, "my best thanks to you for the interest which you have created for my work… As to the why the alkaline earths (Group II elements, [$ns^2$]) as a rule are more ionized than their IP would indicate, I believe I have just got an explanation". Saha was referring to his 'steric factor' (see later). Though expressing satisfaction over it in his reply dated 23 June 1922, Russell had deep reservations about it. This he shared much later (January 24, 1927) with Harold Shapley. To him he wrote, with respect to the barium problem, he had grave doubts of the validity of Saha's steric factor... Unless he misunderstood Saha, he assumed that excited atoms have a sensitive side on which collision must occur to produce effects, and this did not look to him like good quantum physics. The problem, keeping Russell occupied for a long time, had then been resolved by himself.

### 11

June 23, 1922. Russell wrote to Saha that it was a great pleasure for him to have put Saha on the Committee on Spectral Classification of the International Astronomical Union in Rome.

7 September, 1922. Saha suggested a few experiments for King to try. On 12 October, while acknowledging it, Russell wrote, he would welcome more from him on further experiments.

20 December, 1922. Russell drew King's attention to Saha's *Phil. Mag.* [44, 1128 (1922)] paper in which he invoked his "steric factor" to claim that lines of doubly ionized titanium ([Ar]$3d^2 4s^2$, IP 6.82) should be fairly easy to excite. To this Russell's reaction was, "these lines should be more strongly suppressed by potassium than the others, but he would hardly expect to find them in the furnace at all".

1 August 1923. Saha asked Russell for a copy of the sun-spot spectrogram showing the Rb line. 14 November, 1923, Saha was apprised by Russell that recently Adams and A.H. Joy got some spectra of faint dwarf stars which beautifully confirmed his predictions. Detailing further he wrote, the aluminium lines between H and K appeared stronger than the latter pair (which nevertheless were heavy lines). The titanium triplet [2] at $\lambda = 5210, 5192, 5173$ were stronger than the magnesium triplet $\lambda = 5183$ etc. The former were ultimate lines, and the latter belonged to a subordinate series [10]. So everything was just as Saha had predicted. He also added, "I am writing to Dr Adams, asking him to have a copy of the sun-spot spectrum in the red sent to you. You certainly deserve to have one". The same day he wrote to Adams, "I think he (Saha) is certainly entitled to one, and I would be greatly obliged if you would get someone to make a print and send it to him. I would send him simply the piece with the rubidium lines on it, which also shows the important lines of oxygen and potassium, and then send him more if he asks for it. His address is: 92 Upper Circular Road, Calcutta, India". He added, "I have just finished the paper I am writing with Frederick A. Saunders, on the spectra of Ca, Sr, and Ba, and have hit on a rather pretty interpretation of the new terms based on the extension of Lande's theory. This predicts lines of just the types which are observed and practically no others... I hope now to get back to the titanium spectrum, and have some fun with it". As to his request, Adam wrote back to him on November 27, 1923 to say that though Ellerman was away, he could get a print of the rubidium lines made for Saha. The two lines were a considerable distance apart, and as he did not suppose Saha was interested in the intermediate spectrum, he should make two small prints showing the two lines.

## 12

At Calcutta University, Saha's hope for an astrophysical laboratory melted away. There was severe fund crunch as also several other factors. In October 1923 he left for Allahabad. But then, it was only a teaching university. Facilities for physics research were poor. Thanks to some of his friends there, Saha somehow managed to get started. At this juncture he thought of Russell. On 24 September 1924, he sought his help in securing fund from Carnegie or Rockefeller Trust for buying some instruments for astrophysical research. In his reply dated 15 October, however, Russell expressed his helplessness, saying he was not in touch with such funding agencies. He advised Saha to write to Robert Andrew Millikan instead. Saha did so. On 21 October, Millikan informed Russell that C.V. Raman, who had been visiting them had said, Saha was not known for his skill in experiment. Millikan instantly sent Saha a regret letter. Russell's reaction (27 October) to Millikan read, "Some remarks, which Fowler (Alfred) made to me about Saha's attitude while a student at his laboratory, are quite in line with the comments which you have heard." On 10 February 1925, Saha wrote to Russell that he had now turned to the Rockefeller Foundation for fund and had named Russell as a referee. In that letter he also discussed some effects of radiation on ionization.

12 June, 1925. Russell wrote to Adams: "The memoranda for the commission on spectral

classification look to me all right. Saha's paragraph appears to me unexceptionable and, if it is fuller than the previous one, I think it might well be put in."

13 November 1926. Saha to Russell: He would be visiting USA during June-September 1927. Might he know Russell's whereabouts then? To this, Russell replied, it was uncertain.

Meanwhile, in a letter written on 19 July 1927 from Berlin, Saha had advised P.K. Kichlu, one of his students at Allahabad (who later became a Professor in the University of Delhi, and still later, Director of the National Physical Laboratory in Delhi), working in Spectroscopy, to apply for a fellowship of the International Education Board, Paris. Professor Manne Siegbahn of the University of Uppsala had assured him of his help in this matter. Russell was again named as a referee. On 25 October 1927, Russell wrote to one of its officers of the Board, Dr. Augustus Trowbridge: "Kichlu would appear to be deserving but I would decidedly hesitate to recommend his case as one deserving exceptional or special consideration." Kichlu went to Oxford instead.

30 August 1928. Saha congratulated Russell for his "titanic work" on titanium spectra, a piece of work Russell had previously mentioned to Adams.

23 January, 1933. Saha requested Russell to support R.C. Mazumder (another of Saha's students at Allahabad and a noted physicist, who later became a Professor of Physics at the University of Delhi) for an International Research Fellowship of the Rockefeller Foundation. While agreeing (23 February), Russell wrote back that he had finished vanadium arc spectrum work.

26 October, 1934. Saha asked Russell for a copy of Moore's *Compilation of Lines of Astrophysical Interest*. He commended Adam's discovery of coronal lines in Nova Opiuchi 3 though doubting Donald Menzel's identification. On 30 November, 1934, Russell sent Saha a copy of the Moore's. On Menzel's, he agreed with Saha.

17 November, 1935. Saha wrote to Russell, "I have read with much interest your George Darwin Lecture published in the *Monthly Notices*. It was very kind of you to have referred to my early works in such glowing terms". He also informed him of his forthcoming visit to the States some time after June 15 next year on a Carnegie Fellowship. He sent Russell two of his books: *A Treatise on Heat* and *A Treatise on Modern Physics* Vol 1, which, in a letter dated 23 December, Russell much appreciated, especially the spectroscopy part of the latter. About Saha's visit, Russell wrote, mid-summer was not the best time for it. At Princeton, for example, their observatory would remain closed during the long vacation from about 20 June to 20 September, and almost all, if not all, the members of the staff were likely to be absent. However, he hoped, Saha would be able to visit him in Princeton during the University Term, may be in October if he was not much pressed for time on his return. Anyway, Russell was likely to see Saha in Harvard in mid-September on the occasion of Tercentennial Celebration of Harvard College, where Saha was invited, and may be later in Princeton too.

## 13

1936. Saha left Allahabad early and, *en route* England and Europe, arrived in the States in July-end. By then, he had become interested in the physics of ionosphere. When he finally met Russell at Harvard, the discussion mostly centred around ionization of nitrogen. Saha stayed back at Harvard for a while as Shapley's guest.

On 13 July, from Harvard Saha wrote to Russell asking for Adam's data on the spectrum of night sky. Working a lot and publishing only a few, Adams was not wont to share his results with anybody. It is not known if this recourse worked.

There is no further record of Saha's correspondence with Russell until 2 January 1945, when Saha and a few of Indian scientists were about to visit the States as a part of the Goodwill Mission. Saha had previously written to Russell to know if he would be available on 30 January when Saha planned to visit Princeton. On 8 January, we find Russell writing to Dr John A. Fleming, Director of Dept. of Terrestrial Magnetism, thanking him for sending him a copy of Saha's paper "A Physical Theory of the Solar Corona". He said, he was looking forward with much interest to a visit from Saha but did not have his address. If Fleming was in touch with Saha, would he be kind enough to tell him that Russell would be away from Princeton from January 5 to 11, both days inclusive, but should be very glad to see him there after he returned. It seems, Saha adjusted his schedule accordingly.

On 18 January, Russell wrote to Dean L.P. Eisenhart, Nasseau Hall, Princeton Campus advising him that Saha and company desired to meet Professors Einstein, Bohr, Pauli and others. Russell was not sure if Prof. Bohr was there. He wondered as to how they should go about making connections with these worthies and wrote, "Saha is a man of real distinction and should be an honoured guest. We would be glad to entertain him, or it might be that a luncheon could be arranged elsewhere".

## 14

1946-47. Here comes an eye-opener to the western prejudice towards a subject race. On 21 December 1946, Saha wrote a letter to Harry H. Plaskett, the Savillian Professor of Astronomy of the University of Oxford and President of the Royal Astronomical Society, with a request to send copies of it to Edward Milne and S. Chapman. One of them might have sent it to Shapley, and he, in turn, to Russell. Saha wrote from a feeling that he had experienced during his two visits to Britain. It seemed, there had been a persistent effort on the part of British scientists to minimize Saha's early contributions to Astrophysics. This was borne out by Plaskett's remarks in the presidential address published in the *Observatory*, April 1946, where he had said, "Saha, working in Fowler's laboratory after the end of the last War, then demonstrated that the successive appearances of these different spectra could be interpreted as being due to the temperature and pressure prevailing in the stellar atmosphere. His work had in turn been put on a firm theoretical basis by R.H. Fowler and E. Milne, working at Cambridge and using the magnificent material accumulated by Lockyer, and so successfully interpreted by Baxandall".

In the letter Saha retorted, "I regret to tell you that this remark is entirely gratuitous and misleading. It gives one the impression that I derived all the fundamental ideas in astrophysics which goes under my name viz., The Theory of Thermal Ionization and its Applications, from Prof A. Fowler, while I was working as a scholar under him in 1920. This is entirely misleading, for I worked at Fowler's laboratory as a guest, and never registered my name as a scholar and the work had been mainly done in India before I went to Fowler's laboratory. For the information of yourself and other scientists who are of this opinion, I may trouble you with a little biographical sketch". There followed a 10 typed-page long history which is known to most of us where he even added, "I had to encounter at Calcutta the persistent ill will and hostility of C.V. Raman, who had been appointed Palit Professor of Physics in 1917".

Russell's reaction to this letter makes his role in Saha's life crystal clear. On February 13, 1947, to Shapley he wrote, 'Saha's history of life is really interesting, and as good an example I know of the importance of providing assistance to a competent man. I had often wondered why Saha's activity in the theoretical field fell off after his return to India, and his account gives the explanation. Whether he is correct in his opinions about Raman I cannot judge but it is a pity that he was buried earning his living in a small position. Unfortunately the interruption lasted so long that his recent contributions to theory do not seem to me to be at all of the same importance as the old. His history affords a very good argument that the Indian universities and perhaps the government should be actively interested in securing proper opportunities for men of proven abilities. If it would be of any use to you to quote me to that effect you are most welcome to do so. I have always been careful to give Saha the credit for starting the astrophysical application of the ionization theory. I do not think I knew till seeing this letter how much he had done previously in India". It may be mentioned that Shapley, a great admirer of Saha, who had insisted on inviting Saha to the Harvard College Tercentennial celebration actually paid a visit to India a few weeks before he wrote to Russell.

An apologetic Plaskett, while thanking Saha for the letter, replied (7 January 1947), "What was quite new to me was the fact that the early part of your work had been done in India, not Germany, before you came to Fowler's laboratory. The knowledge that you had done so much without help and backing in India only serves to increase the admiration that I have always felt for your great contribution in astrophysics. I only regret that I did not know of this at the time of my presidential address, and can only ascribe my ignorance to a probably incorrectly remembered statement of Russell on his return from England in the early 1920's".

## 15

Here ends the Saha-Russell correspondence. It reveals how the two got on with each other and, in particular, how Russell helped Saha gain recognition in the West. Yet, he never asked Saha to collaborate with him in any of his 26 publications based on Saha's Theory of Ionization. In all these, Saha appeared only as a glory reference. In hindsight, it looks as though while writing to Hale, Saha had nursed a fond hope of working at the Mt Wilson. But Russell had a different game plan. One cannot help notice a certain distance between him and Saha. There is not a single photograph of them appearing together or in a group.

Such is the tale of the two giants. One had opportunities galore with no one to direct him to a focused exploitation of those. The other had plenty of ideas but hardly any means to test them. The two never met in time. When they did, there was nothing for Saha to draw from the meeting. Despite that, much was achieved before that from a kind of "action at a distance". Whether that made or unmade Saha is only a matter of opinion. Regarding the parallel that we drew in the beginning, it may be recalled that Einstein had found in Bose's paper (on Planck's Law) the key he was groping for, off and on, for years. Once he got it, it took no Bose to help him forge ahead. When Bose eventually found the time to see his "Master", he was already famous, and the Master, having exacted as much as he could, had wandered off in search of a new key. To Russell, however, Saha remained a constant source of inspiration for a few years after his seminal work. Russell's paper on Ca, Sr, Ba which he mentioned to Adams on 14 November 1923 was the most important outcome of the symbiosis leading to what we, the students of physics now call the *Russell-Saunders coupling* in complex spectra [Astrophys J., 61, 38 (1925)]. That piece of work is an outstanding craftsmanship of a master. By invoking additional half-integer angular momentum for each electron, Russell not only reproduced the correct terms but also unwittingly ushered in both electron spin and the Exclusion Principle at once. I wonder, if he could ever get there without Saha, and hasten to ask, what if he were a physicist.

## References

[1] *Photosphere* (intensely bright disc of the Sun that we can see with bare eyes); *Chromosphere* : region of glowing gases surrounding the photosphere. During total solar eclipse, when the disc gets masked, red columnar flames are seen to shoot out. These are *prominences*. *Corona*: a bright cloud-like feature a few hundred kilometres above the photosphere.

[2] *Term* (n$\Delta$) refers to one-electron atomic (ionic) level energy, $-R/(n+\Delta)^2$, where n is an integer, R the Rydberg constant and $\Delta$the Rydberg correction with values less than 1, denoted $S \geq P \geq D \geq F \geq$...etc, n an integer (principal quantum number). IS terms means n=1, $\Delta$=S, 2P means n=2, $\Delta$=P, and the like. Singlet and triplet should not taken as multiplicity.

[3] *Enhanced lines:* Lines of elements dominant in the spark (5000K), prominent in the arc (4000K) but fading out in flames (2000-3000K). Examples (all wavelengths are in Angstrom units): $Ca^+$ H (3968), K (3933) bands. In the upper chromosphere (14000km above the solar disk), these dominate. *Hydrogen lines*: $H_\alpha$ (red) $\lambda = 6562.79$, $H_\beta$ (green) $\lambda = 4861.327$; $H_\gamma$ (blue) $\lambda = 4340.47$; $H_\delta$ (violet) $\lambda = 4101.74$. The corresponding *Fraunhofer* lines are called C, F, G, h lines respectively. C line of Fraunhofer 3968 (red region); D band 5896 (yellow region); F-line 4861 (green region); G line 4340 (blue region). Fraunhofer line g of Ca ($\lambda = 4227$) (metallic or arc lines, very strong in flame and arc, but fades out in spark).

[4] Series : *Sharp series* 2P-nS, *Principal series* 1S-nP, n = 2.3.4,..; *Diffuse Series* 2P-nD, n = 3.4.5,...; *Fundamental series* 3D-nF, n = 4,5,6...; An example: Sodium D-lines: A doublet in the *Principal*

*series* of the yellow region of the visible spectrum $3P_{1/2}$ to $3S_{1/2}$ ($\lambda = 5896$); $3P_{3/2}$ to $3S_{1/2}$ ($\lambda = 5890$). Only absorption involving the ground state can be *resonance lines*. The first members of the Principal Series, viz. 1S-2p are *resonance lines* (three components).

[5] *Sun-spots*: areas of local cooling of the photosphere.

[6] *Faculae*: regions of photosphere where temperature is greater than that in photosphere.

[7] Star Groups: O (blue), B (bluish white), A (White), F (Yellow), G (Yellowish red), K M R N (all red); S (extremely dilute nebular fog, T = 3000K). Enhanced lines dominate from right to left in the sequence. Sun belongs to G2 in a scale of G0 to G9 (G10 = K0) between the categories of G-class to K-class of stars, temperature range of K to G being 500-6000K.

[8] *Secondary spectrum* of hydrogen relates $H_2^+$. Saha had also worked on it.

[9] All temperatures are in K.

[10] *Principal lines*: Lines due to transitions between energy levels of a *normal* atom or ion. *Subordinate (lines) series:* involving transitions between levels of *excited* atom or ion.

[11] Additional Note:
*Flash spectrum*. Emission lines seen when the sun disc is totally covered during full solar eclipse. He lines ($\lambda$5876) appear only in flash spectrum, never as Fraumhoffer spectrum.

Atri Mukhopadhyay did his M.Sc. from this Department in 1970, got his Ph.D. in 1978 and was in Denmark, Sweden and England for his post-doctoral studies. He joined SINP in 1985 and retired as Professor in 2006. He was a condensed matter physicist.

# The Early Days of Particle Physics in India

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Elementary Particle Physics – or High Energy Physics, as it is nowadays called – is, in a sense, as old as the atomic theory, i.e. it goes back to Leukippos in Greece and Kaṇāda in India. For the quest has always been the same: to find the elementary constituents of matter, which are believed to be discrete, and to find out how, by interacting between themselves, these particles can conglomerate to form the material world. In modern parlance, however, elementary particles generally mean particles which are 'smaller' than the atomic nucleus and often have such fleeting lifetimes that they can be produced and detected only in highly sophisticated experiments. Not surprisingly, then, modern particle physics grew as an offshoot of nuclear physics and radioactivity studies in the first half of the twentieth century and it was only by the middle of the century that it had begun to assume a separate character.

## Radioactivity and the Nucleus

Radioactivity had been discovered, as everyone knows, by Becquerel in 1896 and later studied by the Curies, and this achieved wide publicity when they jointly received the 1903 Nobel Prize in Physics. At the time, radioactivity was thought to be some sort of fluorescence phenomenon and hence it was considered more a branch of optics. It was the path-breaking experiments of Rutherford and Soddy, carried out at McGill University between 1898–1902, which established it as a sub-atomic level phenomenon, and led to Chemistry Nobel Prizes for Rutherford in 1908 and Mme. Curie in 1911 (and eventually to Soddy in 1921). The existence of the atomic nucleus was announced by Rutherford in a 1911 paper in the *Philosophical Magazine*, where he published his famous scattering formula and showed how it fitted the alpha particle scattering data painstakingly gathered by Geiger and Marsden between 1909–1911. These developments did not go unnoticed in India. The first person to enter the field was a Jesuit priest at the St. Xavier's College in Bombay (now Mumbai), Father Adolphus Steichen, s.j., a Göttingen graduate, who was then teaching at the iconic south Bombay college. With his colleague Father Sierp, he conducted a survey of radioactivity at the hot springs at Tuwa, north of Bombay in 1910, and published a paper on this in the then-highly prestigious *Philosophical Magazine* in 1916. From the point of view of publication, however, Father Steichen had been pre-empted by a chemist, Herbert E. Watson, from the then-new Indian Institute of Science (IISc) at Bangalore (now

Morris W. Travers, the co-discoverer with Sir William Ramsay of the noble gases. As the first Director of the IISc. in Bangalore, he was at pains to build up a strong Chemistry research group there from the start.

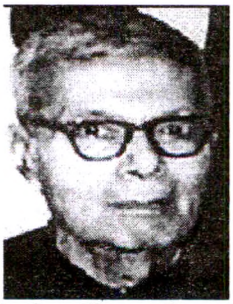
Bengaluru). Watson and his assistants Gosta Behari Pal and W.F.S. Smeeth conducted a series of tests in 1914 of the rocks in the neighbourhood of the nearby Kolar gold fields to see if they exhibited significant signs of radioactivity (in fact, they did not), and published their results in the same year, first in the new *Journal of the Indian Institute of Sciences* and then in the not-so new *Philosophical Magazine*.

Today we would classify these early studies either as geology or as radiation chemistry, but in those days academic disciplines were not so finely tuned. Physicists–and Calcutta University aficionados–will be much more interested in the pioneering work done by Debendra Mohan Bose (1885–1975) in the brand-new Department of Physics, which had just been set up by the University's redoubtable Vice-Chancellor Sir Asutosh Mookerjee (1864–1924) with the help of generous grants from two wealthy philanthropists–Sir Taraknath Palit (1831–1914) and Sir Rashbehary Ghose (1845–1921). D.M. Bose's family credentials were formidable. His paternal uncle, Ananda Mohan Bose, was the first Indian to become a 'Wrangler', after passing the notoriously difficult Mathematical Tripos at Cambridge (1874). His maternal uncle was the famous Sir Jagadish Chandra Bose (1858–1937), whose fame had spread throughout the world for his pioneering contributions to radio communications and to biophysics. Trained first by this savant-uncle at Kolkata and then by stalwarts like Lord Rayleigh, Sir J.J. Thomson and C.T.R. Wilson at Cambridge and London, D.M. Bose came back in India in 1913 with the current research of the times at his fingertips. Appointed the first Sir Rashbehary Ghose Professor of Physics in 1914, he immediately utilised the associated travel grant to visit Erich Regener's cosmic ray laboratory in Berlin for two years. Erich Regener (1881–1955) was the pioneer in balloon flights carrying instruments to study cosmic rays (they had been discovered in 1912) and this induced in Bose a lifelong interest in cosmic rays and their properties. Soon after his arrival there, however, World War I broke out and Bose, as a British subject, was kept in loose internment till the end of the War. However, during this period, he was allowed to continue his research work and was able to develop a highly sensitive cloud chamber (it had recently been invented by his mentor C.T.R. Wilson – in 1911), which he used to photograph recoil tracks of protons produced by fast alpha particles in the chamber. This work was published in the *Physikalische Zeitschrift* in 1916, and was among the evidences quoted at the time to show that the momentum conservation laws hold at atomic scales. Insofar as particle physics grew out of cosmic ray research, Bose may be considered the first Indian particle physicist.

Debendra Mohan Bose was the Sir Rashbehary Ghose Professor of Physics (1914–1938) at the University of Calcutta, and the pioneer of cosmic ray research in India.

Returning to India in 1919 after the War, Bose resumed his position as Ghose Professor at the University of Calcutta. The Department of Physics then was a really stellar one. Apart from Bose, there was C.V. Raman (1888–1970), whom Sir Asutosh had personally lured away from the Indian Financial Service in 1917 and appointed Sir Taraknath Palit Professor of Physics – at half his previous salary. Among his doctoral students was Sisir Kumar Mitra (1890–1963), who had joined the Department in 1917 as Lecturer, and was later to become the Khaira Professor of Physics in 1923. Another student of Raman was Bidhu Bhusan Ray (1894–1944), who was to found the school of X-ray spectroscopy in Calcutta[1]. Between 1917 and 1919, two young Turks joined the Department of Physics as Lecturers. They were Satyendra Nath Bose (1894–1974) and Meghnad Saha (1893–1956), who had completed their M.Sc. degrees in 1915 and stayed within the University. It was D.M. Bose, rather than Raman, who acted as a mentor for these two brilliant young men[2], and gave them rare texts out of his personal collection to read, such as Planck's *Thermodynamics*. This proved the initial stimulus for the great discoveries which these two were soon to make.

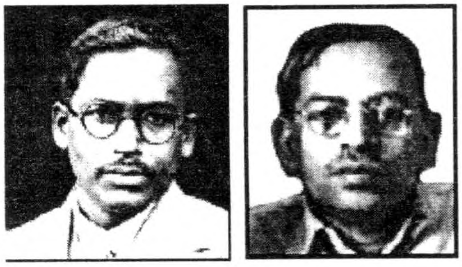
D.M. Bose continued his studies on alpha particle scattering in Calcutta during the 1920s. With his student Subodh Kumar Ghosh, he built the first cloud chamber to operate in India. This operated till 1941, when a better one was built under his tutelage by M.S. Sinha and R.L. Bhattacharya at the Bose Institute. Meanwhile, theoretical studies in nuclear science had been initiated by an obscure teacher in the Maharaja's College at Jaipur. M.F. Soonawala, a man of wide interests in physics, published a speculative paper in the *Indian Journal of Physics* in 1928, in which he speculated that nuclei are successively built out of protons, electrons and the nuclei of inert gases (the neutron was still a tentative hypothesis put forward only half-seriously by Rutherford in 1920). Soon to follow from Allahabad University were applications of the new ideas of quantum mechanics to nuclei by Amiya Charan Banerji (1891–1968), a Cambridge-trained Wrangler, fresh from his studies in Britain. Banerji was probably the first Indian to develop the quantum theory of scattering and use it to try to infer the nature of the nuclear potential from data on alpha particle scattering (1930). At about the same time (1930-31), another Wrangler, the mathematician Bhupati Mohan Sen, then an obscure Lecturer at Rajshahi College in modern Bangladesh, wrote a couple of papers in *Nature* and the *Philosophical Magazine* on the intriguing subject of beta decay. At the time, just before the discovery of the neutron, the major beta decay puzzle was how electrons confined in the nucleus could acquire the energy found in beta rays. B.M. Sen tried to explain this by an application of special relativity to the energetics of beta rays. By 1933, the neutron had been found, and we find Sen, then in Calcutta at Presidency College (of which he was later to become the first Indian principal from 1931 to 1942), publishing in *Nature* a small proof that the neutron is a Dirac fermion.



Amiya Charan Banerji (1891–1968) was the first Indian to apply quantum mechanics to atomic and nuclear physics.

## The beginnings of Particle Physics in India

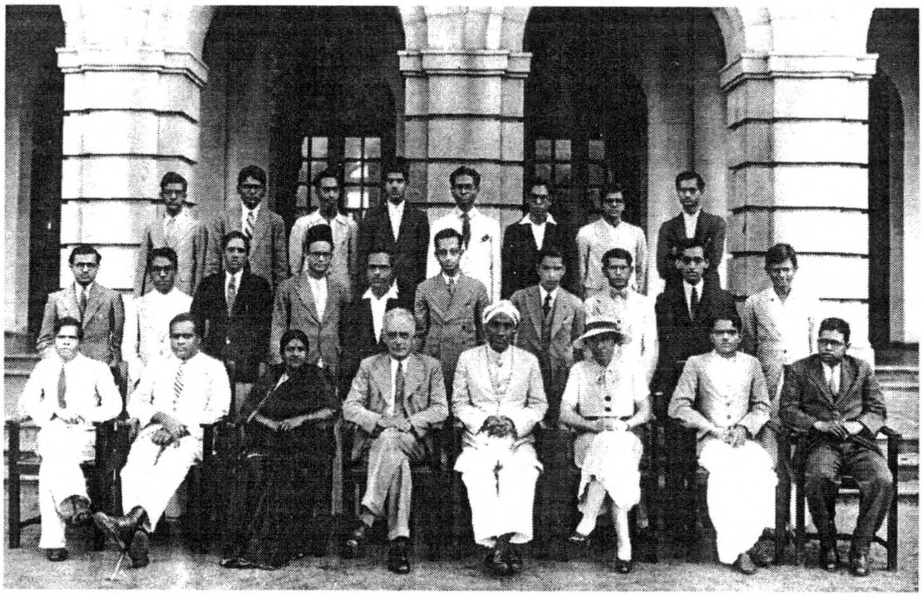
The first Indian paper that can be properly classified as a particle physics paper was actually



Meghnad Saha (1893–1956) and D.S. Kothari (1905–1993) published the first Indian paper on particle theory from the University of Allahabad in 1933,

written by Meghnad Saha and a young 'demonstrator' Daulat Singh Kothari (1905–1993) from the University of Allahabad. Saha, who never got along with Raman, had left Calcutta in 1923 and moved to Allahabad University, where he had slowly and steadily built up a group of young researchers around him. Perhaps it was the enthusiasm of his young colleague Banerji which got him interested in nuclear physics. Be that as it may, in 1927-28 Kothari and Saha addressed the famous problem of the beta particle energy distribution. Briefly stated, the problem is this: if the beta electron arises from the two-body decay of a neutron to a proton and an electron, its energy should have a fixed value. However, observed beta particles have a wide range of energies. This was a serious puzzle in the 1920's, and even led Niels Bohr to declare that the principle of conservation of energy may be violated at the nuclear scale. Wolfgang Pauli famously solved this by postulating that 'invisible' neutrinos were created at the same time as the beta electron, and these carried away the missing energy. However, in 1930, when Pauli's proposal was made, not many were willing to buy this hypothesis, and Pauli came in for quite a bit of ridicule. Saha and Kothari, however, came up with an alternative solution which was simpler and equally plausible. Noting that in most nuclides, a beta decay is accompanied by emission of a gamma photon, they claimed that the basic process was a gamma emission, where some of the photons underwent a pair creation in the electromagnetic field of the nucleus. Of this pair, one was emitted as a beta ray and the other was absorbed (together with a variable amount of energy and momentum) into the nucleus. This beautifully explains why the beta particles have varying energies, and eventually *Nature* was happy to publish their letter in 1933. By then, Kothari had left Allahabad to do his Ph.D. in Cambridge. Saha pursued their idea for some time, but the departure of his bright young collaborator, and, more importantly, the arrival in 1934 of Enrico Fermi's theory of beta decay, which incorporated the Pauli hypothesis and explained the shape of the beta ray energy spectrum, dampened his enthusiasm. The detailed measurements of the beta energy spectrum by Franz Kurie and others, published in 1936, set the general seal of approval on the Fermi theory, and the Kothari-Saha theory, like so many others, fell by the wayside. However, one must accept that it was a brilliant idea at the time it was conceived.

The 1930's were somewhat of a roller coaster for nuclear-particle research in India. Apart from the Kothari-Saha paper, there was a brief excursus by the great Max Born, who visited[3] the Indian Institute of Science in the winter of 1935-36, and wrote a paper with N.S. Nagendra Nath on a then-fashionable idea floated by de Broglie that the unit-spin photon is a bound state of a spin-half neutrino and its antiparticle. Addressing the Indian Science Congress in 1936, Meghnad Saha put forward a theory of the difference between the proton and neutron



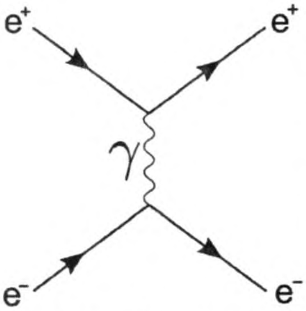
At the IISc in 1936 Sir C.V. Raman and Lady Raman with Professor and Frau Max Born. [Courtesy: Archives of the Raman Research Institute, Bengaluru].

masses based on the assumption that the neutron was a bound state of two magnetic monopoles. Both of these theories were proved wrong, of course, but the idea has kept popping up ever since in different contexts–with varying degrees of success. There were several routine works by spectroscopists like Venkatesachar and Subbaraya from Bangalore. From Presidency College, Calcutta, came a series of papers by Kulesh Chandra Kar (1899–1990) and his students, developing a theory pursued by Kar, that the nucleus itself had an atom-like structure, with a hard core and outer shells of alpha particles. This idea, suggested by Rutherford with his usual uncanny insight, may be considered the precursor of the nuclear shell model, eventually developed in 1949. The 1930's work of Kar and his collaborators, who basically used the Schrödinger equation to solve for 'nuclear wavefunctions', was too naïve to describe the real nucleus, but it was considered cutting-edge research for the times.

The departure of Raman in 1933 to become Director of the IISc, and the joining of Meghnad Saha as Palit Professor in 1938 may be regarded as a watershed in the history of physics at Kolkata. Gone was the Nobel Laureate, with all the arrogance and aura associated with that distinction, and in his place came another brilliant man, now in his mid-forties, with very decided views on how science and technology should proceed in India. In turn, IISc gained, after a couple of undistinguished Directors, a man of great vision and immense dynamism. Despite the Born fiasco, the effect of being led by a first-class physicist soon made an impact on the physics done at the IISc The only straight loser in this was Allahabad University, which was never again to rise to the top rank, even thought it continued to produce first class students, of which Harish Chandra is a famous example.

## Homi Bhabha at Cambridge

Homi J. Bhabha (1909–1966) during his Cambridge days.



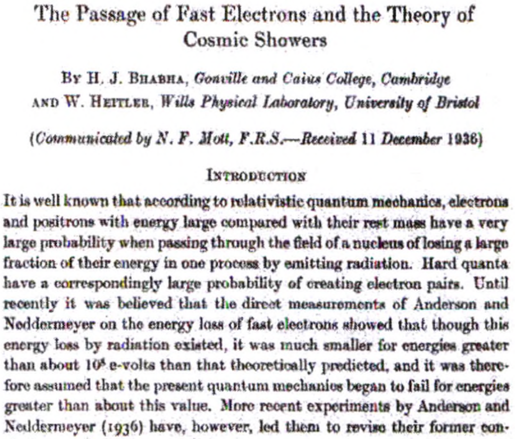
Lowest order Feynman diagram for Bhabha scattering in QED.

By far the most impressive work done in nuclear-particle physics by any Indian during the 1930's was undoubtedly done by Homi Jehangir Bhabha (1909–1966), a young Parsee who was closely related to the famous industrial house of the Tatas. Sent to Cambridge by his wealthy parents to become an engineer–destined to work in the iconic iron and steel industry set up by the Tatas–the young Bhabha rebelled and soon enrolled himself for the Mathematical Tripos, which he cleared in 1932 with a first class, adding one more to the distinguished list of Wranglers from India. Bhabha was something of a protégé of Paul Dirac, the taciturn genius of Cambridge, and his stellar performance in the Tripos and afterwards won him the Rouse Ball Studentship (1932–1934) and the Isaac Newton Studentship (1934–1937) at the famed Cavendish Laboratory, the first Indian to work there since D.M. Bose. Using these, he was able to live and work in Europe during the momentous days of the 1930's, when the physics scene was as bright as the political scene was gloomy. Among his mentors were Niels Bohr, Wolfgang Pauli and Enrico Fermi.

It was the newly-exciting field of cosmic ray physics which Bhabha chose for his field of activity and he started with a bang. His 1933 paper in the *Zeitschrift für Physik*, entitled "On the absorption of cosmic rays" acknowledges discussions with the great Wolfgang Pauli in the Introduction itself. Studies of the passage of fast protons–such as would be produced in the Cockcroft-Walton generator, invented at Cambridge in 1932—followed. But it was his 1936 paper, published in the *Proceedings of the Royal Society*, that will remain his greatest claim to fame. Entitled "Scattering of positrons by electrons with exchange on Dirac's theory of the positron", it was his first solid calculation in what would eventually become Quantum Electrodynamics (QED) and will remain enshrined forever in the textbooks as Bhabha scattering. Modern readers, who regularly calculate this as a graduate exercise, require to appreciate that Bhabha approached this problem long before the days of Feynman diagrams, when everything had to be calculated from first principles. Even the principle of second quantization was just three years old, having been invented by Pauli and Weisskopf in 1933. It had, however, already been applied to electron-electron scattering by Neville Mott (non-relativistic case) and by Christian Møller (relativistic case). Bhabha made a new departure by considering the positron–an antiparticle. His paper pointed out that the difference between the predicted scattering cross-section for a positron treated as an independent particle, and a positron treated as an antiparticle of the electron, were considerable. Later experiments matched the latter hypothesis perfectly. Bhabha's work, therefore, completed the discovery of antiparticles, which had been initiated by Dirac's 'hole theory' of 1927.

Walter Heinrich Heitler (1904–1981) was already a distinguished physicist when he met Homi Bhabha in 1933.

Walter Heitler (1904–1981), a Max Born protégé from Göttingen, who had already become famous for his studies with Max London of the helium atom wavefunctions, moved to Bristol in 1933–another Jewish refugee from the Nazi regime. Heitler was a skilled exponent of second quantization, and was soon (1936) to compose his famous "*Quantum Theory of Radiation*", which was to become a classic textbook in the subject for decades. Bhabha met him in 1933, and soon found a useful collaborator, for both young men were deeply interested in cosmic rays. Both of them had been working on the interactions of high-energy electrons. Heitler, working with Bethe had already calculated the expected energy loss by a fast-moving electron in the field of a nucleus (like nitrogen or oxygen present in the air) using the new QED, and by these estimates, such an electron could not travel much more than about 2 Km even in rarefied air before losing all their energy and getting captured by some atom. However, fast-moving electrons are regularly produced in cosmic ray interactions at the top of the atmosphere, and are found at sea-level, some 8 Km down. How do they get so far? Most of the experts simply thought the Bethe-Heitler computation was wrong–not that they distrusted so formidable an expert as Hans Bethe, but they thought that QED itself was flawed[4]. This was the problem tackled by Bhabha and Heitler. Bhabha had already talked with Hugh Carmichael, then Cambridge's top authority on cosmic rays, and it was Carmichael who had told him of an idea floating around in those days that perhaps the initial electron touched off a cascade of electrons, just as an avalanche starts from a single stone falling. Heitler had had a similar conversation with Lothar Nordheim in 1934. None of these senior scientists had thought it worth doing any calculations based on these ideas, because they distrusted QED anyway. Bhabha and Heitler, with the naïveté of youth, set themselves to do just that–to calculate the probability, using QED, that a fast-moving electron could lose so much energy in the presence of a nucleus in the form of gamma photons, that the same photons would then create an electron-positron pair, which would be fast-moving themselves, and give rise to more photons, more electron-


The Passage of Fast Electrons and the Theory of Cosmic Showers

By H. J. Bhabha, *Gonville and Caius College, Cambridge*
and W. Heitler, *Wills Physical Laboratory, University of Bristol*

(*Communicated by N. F. Mott, F.R.S.—Received* 11 *December* 1936)

Introduction

It is well known that according to relativistic quantum mechanics, electrons and positrons with energy large compared with their rest mass have a very large probability when passing through the field of a nucleus of losing a large fraction of their energy in one process by emitting radiation. Hard quanta have a correspondingly large probability of creating electron pairs. Until recently it was believed that the direct measurements of Anderson and Neddermeyer on the energy loss of fast electrons showed that though this energy loss by radiation existed, it was much smaller for energies greater than about $10^8$ e-volts than that theoretically predicted, and it was therefore assumed that the present quantum mechanics began to fail for energies greater than about this value. More recent experiments by Anderson and Neddermeyer (1936) have, however, led them to revise their former con-

Facsimile of the beginning of the Bhabha-Heitler paper in the *Proceedings of the Royal Society* (1937). [Courtesy: TIFR Archives] positron pairs and so on in a cascading effect. They found that it was easy to get electrons even after 8 Km–though, of course, it was a different electron from the original one. Thus was born the celebrated Bhabha-Heitler theory of cosmic ray showers (1936). A year later, Carlson and Oppenheimer published the same idea in the *Physical Review*[5]. But Bhabha and Heitler had beaten them to the punch.

During the next few years, Bhabha worked feverishly at Cambridge on the subject of cosmic rays and their interactions. During these years he really had the Midas touch, for every investigation yielded results of profound import. He continued to develop the theory of cosmic ray showers with Heitler, learned experimental cosmic ray observations from Carmichael and investigated the Yukawa theory of nuclear forces, predicting the $\rho$ meson twenty-three years before Sakurai, who is generally credited with the prediction. In 1937 came some brilliant observations on the 'penetrating radiation' in cosmic rays, which Oppenheimer and Serber had identified with the Yukawa meson, as due to an entirely new particle. Bhabha's masterly observation that the long lifetime of the muon–which this particle really is–can be explained as a result of time dilation, was a beautiful vindication of special relativity, then under severe attack from Einstein's Nazi detractors as 'Jewish physics'. Today it is a standard undergraduate exercise, but rarely do today's teachers realise that in Bhabha's time it took courage and insight to make this claim.

In the summer of 1939, as war clouds hovered over Europe and the world, Homi Bhabha came back to Bombay to enjoy a summer vacation with his parents. He was due to return to Cambridge at the end of the summer, but in the meantime the Second World War broke out and civilian passage on ships was immediately banned because of the German U-boat menace. Just as D.M. Bose found himself stuck in Germany during the First World War, Bhabha–very much a Cambridge man in those days–found himself stuck in India. As there was no knowing when the War would end, he started seeking a position in India, and was promptly snapped up by C.V. Raman, the new Director of the IISc, as a prize catch.

Bhabha was never to return to Cambridge, except for short visits. His IISc experience showed him how science lagged behind in India because of the lack of first class facilities. To counter this, he set up the Tata Institute of Fundamental Research (TIFR) in 1945, with a generous endowment from the house of the Tatas. Increasingly, he became an institution builder and a science manager, cutting a wide swathe through the scientific community until his untimely death at the age of 57 in an air crash. Elegant theoretical work was still to come from this brilliant mind, but somehow, it never managed to reach the heights of his phenomenological work at Cambridge.

Bhabha was nominated for the Nobel Prize five times. Interestingly, every time it was by the French mathematician Jacques Hadamard and not by any of his Cambridge cronies[6]. However, competition was tough in those days, and he lost out, successively, to Cockcroft and Walton, Frits Zernike, Max Born and Walter Bothe, Lamb and Kusch and finally, the transistor trio, Bardeen, Brattain and Shockley.

It is idle to speculate what Bhabha might have done had he gone back to Cambridge after the War. He would have been 36 years old and, with Indian independence in the offing, it would have not have been easy to get a position on the faculty there. Instead, he was Director of his own Institute, which he could build up as he liked, and that is just what he did. If TIFR– and indeed the whole of post-independence Indian science – has fallen short of Bhabha's dream of a new Cambridge and a new Paris, surely it cannot be blamed on that extraordinary man.

## The Sandakphu experiments

The Indian Science Congress has been initiated in 1914 by two British chemists, J.L. Simonsen and P.S. McMahon. The first session took place at the Asiatic Society in Calcutta, with Sir Asutosh Mookerjee as President. In 1938, the Silver Jubilee of the Science Congress was planned on a grand scale, again in Calcutta. Though the earlier sessions had been largely attended by scientists working in India, this time several eminent scientists from abroad were invited, and the President was supposed to be none other than the celebrated Lord Rutherford. In fact, however, Rutherford died that year, before the Science Congress was held, so his place was taken by another famous Briton, namely Sir James Jeans. Among the other invitees to the Congress were Walter Bothe (later a Nobel Laureate) and Sir Geoffrey Taylor. Of course, Indian luminaries like Sir C.V. Raman, Meghnad Saha, S.N. Bose and D.M. Bose also attended. In the cosmic ray session, there was a lively discussion on detection of cosmic ray particles, in which Bothe and Taylor took a leading part. One of their suggestions was that cloud chambers could eventually be replaced by stacks of photographic plates as cosmic ray detectors. These would be much more robust and would work even in low pressure conditions, such as on balloons and on high mountains. The technique had already been developed in Austria by Marietta Blau (1894–1970) and her student Hertha Wambacher in 1937. This struck D.M. Bose, whose cosmic ray interests had so far revolved around the cloud chamber, so forcefully, that when the Congress was over, and the distinguished guests had left, he decided to put his student Biva Choudhuri to making cosmic ray studies with photographic plates. To get a high altitude, they travelled to the 12,000 ft peak of Sandakphu, in the Darjeeling Himalayas (nowadays a popular trek, but then a remote place).

Marietta Blau (1894–1970) pioneered the use of photographic emulsions to detect particle tracks in the mid-1930s. Her career took a severe beating when she had to flee Austria in 1938 because of her Jewish background and seek a job in Mexico. Though she later ended up working in many top institutions, she was never to come back into the forefront again.

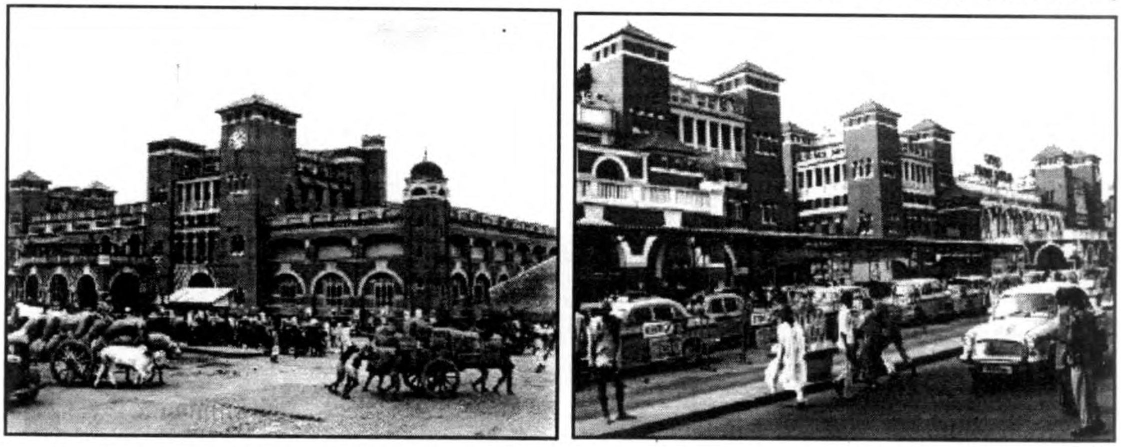
In these Sandakphu experiments, Bose and Choudhuri exposed a stack of 'Ilford plates', which were glass plates, coated with photographic emulsion–a colloidal solution of silver bromide or silver iodide in gelatin–from which the photographic negatives used to be made.

The manufacturer, Ilford Ltd. had been set up in 1879 and still exists (though it is now Japanese-owned). The 'Ilford plates' came in two varieties–the 'halftone' plates, which were coated on one side only–and the 'fulltone' plates, which were coated on both sides. Obviously the fulltone plates gave better resolution than the halftone ones, but they were also much more expensive. In any case, as soon as the World War broke out, all the fulltone plates were requisitioned for war use, where they would prove invaluable in aerial reconnaissance of the kind used, famously, to 'sink the *Bismarck*'. The experiments of Bose and Choudhuri were done, therefore, with halftone plates, and this made their finding much less accurate than they could otherwise have been.

Wooden box containing glass photographic plates

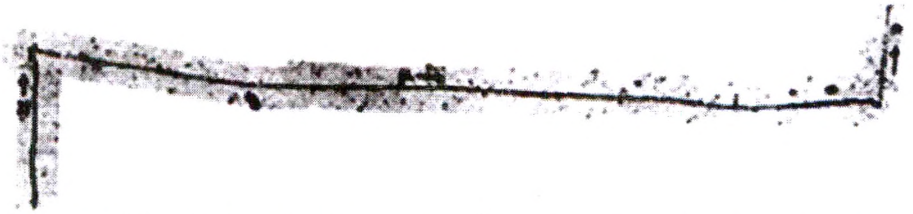
It is worth noting that Bose and Choudhuri were not the pioneers of photographic emulsion technique in India. That had been started by two teachers of Wilson College, Bombay, V.D. Dabholkar and H.J. Taylor, a former student of Rutherford, who had mainly applied this to the study of radioactive disintegrations. However, in a 1938 paper, they did attempt a study of cosmic rays, exposing plates at sea level in Bombay and at high altitudes in Kashmir. The work of Bose and Choudhuri was, however, of much more significance. Nevertheless, it is worth noting that in those days undergraduate teachers in Wilson College could find time from their heavy teaching duties publish repeatedly in *Nature*–something which has, alas! not been replicated in post-independence India...

Studying their exposed prints, Bose and Choudhuri found the usual 'disintegration stars', many tracks which were clearly due to protons and another set of tracks, which they immediately identified (1940) with the 'mesotron'–the exchange particle of Yukawa, which we today call the pion. A pion candidate has been discovered by Anderson and Neddermeyer in 1937, and Oppenheimer and Serber had hailed it as the Yukawa exchange particle. But a series of studies–


The contrast between the halftone print on the left and the modern digital photograph on the right is clear even at this reduced size.

one by Bhabha, but more notably by Bruno Rossi and the trio of Conversi, Pancini and Piccioni– had led to the conclusion that this particle interacted too weakly with nuclei to be the Yukawa particle. Bose and Choudhuri were quite sure, however, that they had discovered the Yukawa particle. A series of papers in *Nature* followed (1941–1944), in which they discussed indications that the tracks were indeed those of the 'mesotron', and that its mass was indeed in the right ballpark[7]. In 1945, Biva Choudhuri wrote her Ph.D. thesis on her discovery of the 'mesotron'– a truly landmark thesis, which never got the recognition it deserved.

In 1945, the War in Europe ended and most of the European and American scientists gradually drifted back from war work to their old research. Thanks to the vital contributions of scientists to the war effort (Bletchley Park, Manhattan Project, etc.), Governments were very kindly disposed to science at the time. Thus both Ilford and Kodak were instructed to produce special fulltone plates with a high density of silver halide, and optical companies were instructed to produce better microscopes for plate scanning. The cosmic ray group led by Cecil Powell (1903–1969), at the H.H. Wills Laboratory of the University of Bristol, reaped the full benefits of this technology. Powell had been initiated into emulsion-based research by none other than Walter Heitler, who knew Blau and Wambacher, but nothing exceptional came out of their work. Now, after the War, he was joined at Bristol by the dynamic young Brazilian Césare Lattes, who also brought into the collaboration his former teacher Guiseppe Occhialini (already famous for his work with Blackett on the 'coincidence technique', which was to win Blackett his Nobel Prize). When this group of researchers[8] exposed their high-density plates to cosmic rays, they were astounded to find a whole new world of tracks where none could be seen before. In the words of Powell "*It was as if, suddenly, we had broken into a walled orchard, where protected trees had flourished and all kinds of exotic fruits had ripened in great profusion.*" And among these exotics, they found the clue to the mesotron problem. There were actually *two* mesons, fairly close in mass, one of which decayed into the other. Today we write this reaction as. Subsequently, the muon decays as. We see the evidence of the charged particles, and in the 'golf-stick tracks' which established the existence of the pion as an independent entity.

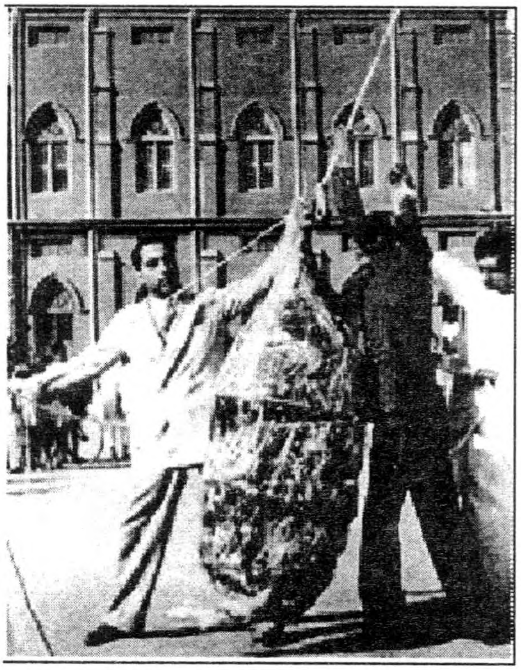


Photographic negative, showing a typical decay chain of a pion (L) to a muon (C) to an electron (R), with invisible neutrinos carrying away the missing momentum (Powell 1948).

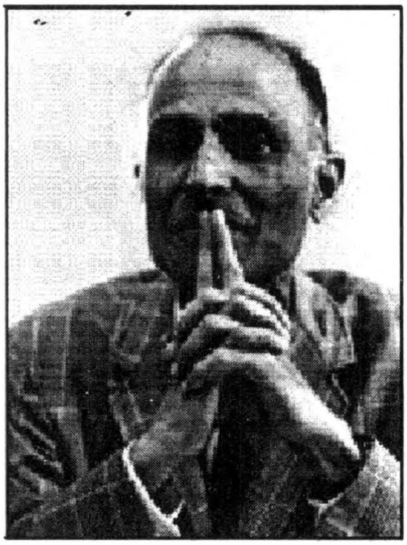
Supervising Biva Choudhuri's thesis was really D.M. Bose's last hurrah in cosmic ray work. His brilliant student went away to Bristol to work in Powell's lab, where there were so much better facilities. Bose himself faded into celebrity as Director of the Bose Institute (succeeding his famous uncle, the founder), President of the Indian Science Congress Association and a host of other high-sounding titles. In 1950, Cecil Powell walked away with the Nobel Prize *"for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method"*. Lattes, whose idea of using boron-impregnated emulsion had yielded the beautiful tracks seen by their collaboration, was not considered, since the Nobel Committee (then) considered only the head of the collaboration. Marietta Blau was nominated, but not awarded, probably because her collaborator Wambacher was notorious as a Nazi. Bose and Choudhuri were simply ignored. Perhaps the Nobel Committee felt that it was muons that they had seen and measured, and not pions. Biva Choudhuri continued to publish in the UK at least till 1950. Then she disappears from view. Even the landmark volume on Indian women scientists, *Lilavati's Daughters* (2009), does not feature her name.

## Cosmic Ray Research at Bangalore, Bombay and Ahmedabad

While the Sandakphu experiments were being conducted, Homi Bhabha started a cosmic ray unit in Bangalore with whatever resources could be scraped up in wartime India. At last, he could lead his own experimental team and put what he had learnt from Carmichael and others to good use. Bhabha and his team pioneered balloon flights with cosmic ray detectors in India, and made many good and useful measurements of cosmic rays using the advantages offered by India's low latitudes[9], but were not fortunate enough to make new discoveries. The poor quality of equipment available in India at the time could have been a reason, as we have seen in the case of Bose and Choudhuri. The absence of discussions with experts like Rutherford, Wilson, Cockcroft, Carmichael and others may have been a more potent reason.


Homi Bhabha launching a 'cosmic ray telescope' from the central quadrangle of the IISc, some time in the 1940s.

In Bangalore, however, Bhabha was also free to exercise his bent for theory. A 1940 paper in the *Proceedings of the Indian Academy of Sciences* discusses the possibility of Dirac fermions of charge greater than unity, something which seemed, in those early days of QED, to have problems. Bhabha pursued this for a couple of years and then moved to integral spin. In B.S. Madhava Rao (1900–1987), who had just joined the Central College, Bangalore with a D.Sc. in Applied Mathematics from the University of Calcutta, the mathematician in Bhabha found a kindred soul to bounce ideas off. This theoretical interest led, in 1941, to the Bhabha-Corben equations for an integer-spin particle, and later, in 1946, to the Bhabha equations for a particle of arbitrary spin. From such early efforts sprang the application of group theory to wave equations and then quantum field theories, ultimately leading to the momentous discoveries of Gell-Mann and Nishijima in the 1950s. By then, of course, Bhabha was a celebrity and an institution builder, and had no time for such trifles. Perhaps his greatest contribution to theoretical science from his Bangalore days was to train the young Harish Chandra, and send him to Dirac at Cambridge, from which ultimately emerged Harish Chandra's classic works on group representation theory.

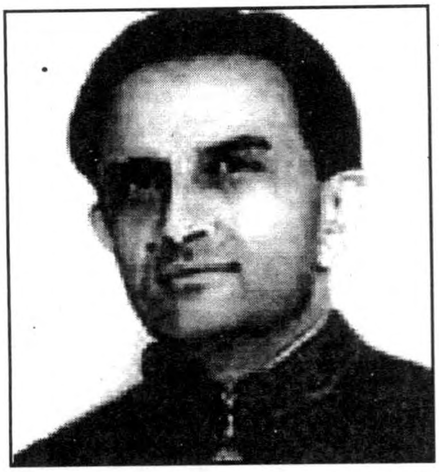


Harish Chandra (1923–1983) started as a particle physicist with Bhabha in the 1940s, moved on to become a mathematical physicist with Dirac and finally a pure mathematician at Princeton.

Another rising star in the IISc in those days was Vikram Ambalal Sarabhai (1919–1971). Born, like Bhabha, into a wealthy family, he too travelled to Cambridge and passed the Mathematical Tripos in 1940. Sir C.V. Raman, with his usual nose for spotting an extraordinary talent, immediately brought the fresh graduate back to India to join the cosmic-ray unit at the IISc. The supremely confident youth worked in the same place as a luminary like Bhabha with mutual respect, but without getting drawn into his orbit. In this, he had the full support of their mentor, Raman. Not so much the elementary particles in cosmic rays, but the influence of the Earth on them was the interest of this young savant. Six single-author papers[10] on this topic came from Sarabhai during his Bangalore period during which he studied the diurnal and annual variation of cosmic ray intensities and ways to separate the primary from the secondary cosmic rays. In 1946, when the War was over and Bhabha and his team had moved to Bombay, Sarabhai decided that it was time for him to go abroad again. Back to Cambridge he went, and soon earned his doctorate with a thesis entitled *Cosmic ray investigations in tropical latitudes*, which was based on his Bangalore measurements. Armed with his new degree, Sarabhai came back to newly-independent India, all of 28 years old, to found a new institute, just as Homi Bhabha had done two years previously. Called the Physical Research Laboratory (PRL), this was started in November 1947 with contributions from a few philanthropic societies controlled by his family and friends. PRL started in a small way, in a few rooms of the M.G. Sciences Institute at Ahmedabad, which had been founded by Sarabhai's parents. Bhabha had started TIFR similarly–in Kenilworth, a sprawling bungalow in Bombay owned by his aunt. It is certainly useful to be well-connected!

Though he was the founder of his new Institute, Sarabhai did not want to become its Director. The post was filled by K.R. Ramanathan (1893–1984), a meteorologist who had once done a D.Sc. with Raman, but was then about to retire as Director of the Indian Meteorological

Department. Sarabhai remained in PRL as a Professor, supervising no less than 19 students for Ph.D.'s in cosmic ray physics and related topics, including U.R. Rao (b. 1932) who would later preside over India's conquest of space in the 1990s. Only in 1965, when Ramanathan retired at the age of 70, would Sarabhai become Director of PRL, a position which he retained till his untimely death in 1971.



Vikram Sarabhai founded the Physical Research Laboratory (PRL) in Ahmedabad in 1953 as a cosmic ray research unit. He later went on to become the father of India's space research programme. He was also the founder of the Indian Institute of Management. at Ahmedabad. His early death at the age of 52 has been attributed to sheer overwork.

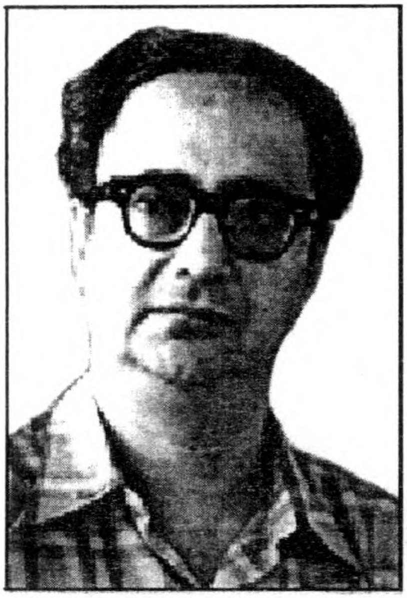
Unlike the stately Bhabha, however, Sarabhai always retained the common touch, and even when Director, was often seen in his lab in casual clothes, working with his students as if he were one of them. Gradually his interests expanded from cosmic rays to planetary magnetic fields, from planetary magnetic fields to solar physics, from solar physics to satellite-based observation and eventually to the launching of satellites. This led him to become the father of India's space programme, just as Homi Bhabha was to become the father of India's atomic energy programme. The Indian National Committee for Space Research (INCOSPAR) was set up in TIFR in 1962 under the chairmanship of Sarabhai (In 1969, this became the separate Indian Space Research Organisation (ISRO), with Sarabhai continuing as Chairman), with full support from Homi Bhabha, who was the Director of TIFR. All this came to an abrupt end when the 52-year old Sarabhai, then at the height of his career, went to sleep one night and never woke in this world again. It must be said that though the direct cosmic ray work of Sarabhai will not be quoted forever, as will be the Cambridge-period work of Bhabha, the *Chandrayaan* and *Mangalyaan* projects would not have taken place if the youthful Vikram Sarabhai had not looked up at the skies and wondered where the mysterious cosmic rays were coming from.

In 1945, when Sarabhai went back to Cambridge to write his thesis, Bhabha had moved from Bangalore to Bombay, where he had just founded the TIFR, and his cosmic ray group had moved with him. It then included B.V. Sreekantan (b. 1925), who was later to head the TIFR in the 1980s, Yash Pal (b. 1926), who later became Chairman of the University Grants Commission of India, and Devendra Lal (1928–2012) who would later become a prominent geophysicist and one of the builders of the Scripps Institution of Oceanography at the University of California at San Diego. In the 1950s, the group was enriched by the addition of M.G.K. Menon (b. 1928), a former student of Powell, who would later go on to become Bhabha's successor as Director of TIFR. An even bigger catch was Bernard Peters, originally Bernhard Pietrkowski (1910–1993), a Polish-born cosmic ray expert, whose parents had fled from Poland to Germany because of the Russian domination. Peters himself had to flee Germany because he was Jewish (escaping from the dreaded Dachau concentration camp) and ended up in the USA, doing his Ph.D. with Oppenheimer at Berkeley in 1942. From 1942 to 1945, he worked on the Manhattan project, but, like so many others, he was deeply upset by its consequences. Moving to Rochester, Peters involved himself deeply in cosmic ray studies, which was as far from weapons research as he could get. However, he soon found himself under the scanner of the then-ubiquitous Un-American Activities Committee, under the leadership of the ferocious Senator Joe McCarthy. It was the time when the Rosenbergs were on trial for their lives, which they were soon to lose on the electric chair. Peters was a declared communist, a nuclear physicist and a student of Oppenheimer to boot. Fortunately, around this time, Peters met Homi Bhabha, who invited him come to India to join the TIFR and develop cosmic-ray observations there. In 1951, therefore, Peters moved to Bombay, out of the reach of Senator McCarthy and his sniffer dogs. The cosmic ray work in TIFR in the 1950s is really the story of Peters and his group, for by then Bhabha had been roped in by the Prime Minister, Jawaharlal Nehru, to set up India's atomic energy programme. Peters and his team did solid bread-and-butter work in cosmic ray observations, but the great 1950s discoveries in particle physics–antiparticles galore, strange particles, neutrinos, parity violation, flavor mixing–were all made elsewhere. With hindsight, we can see that this was partly because Peters directed some of the effort away from elementary particles to cosmic-ray produced exotic isotopes, which was his primary interest. However, as Arthur C. Clarke famously said, discoveries are made by serendipity, and that quality has been largely missing in almost all of post-independence Indian science.

Bernard Peters led the TIFR cosmic ray programme (1951–1958) while Bhabha was busy setting up the Atomic Energy Commission and the BARC.

## The Kolar Experiment

Perhaps the most notable experimental work done by TIFR in the field of cosmic rays, and in particle physics in general, was to set up a cosmic ray observatory in the depths of the Kolar gold mines, at the great depth of 2.3 Km below the surface. Kolar is only about 66 Km to the east of Bangalore, and the significance of having a very deep mine there had not escaped the eagle eye of Homi Bhabha, even in his Bangalore days. In 1948, he sent his student, B.V. Sreekantan, down the Champion Reef mine at Kolar to measure the cosmic rays flux at depths of 1000 feet and more. The purpose was to see if, after passing through that much depth of solid rock, the cosmic rays consisted only of muons, or there were other components as well. To assist him, Sreekantan soon had S. Naranan and P.V. Ramana Murthy, young students who had joined the cosmic ray group at TIFR after completing their M.Sc.'s.

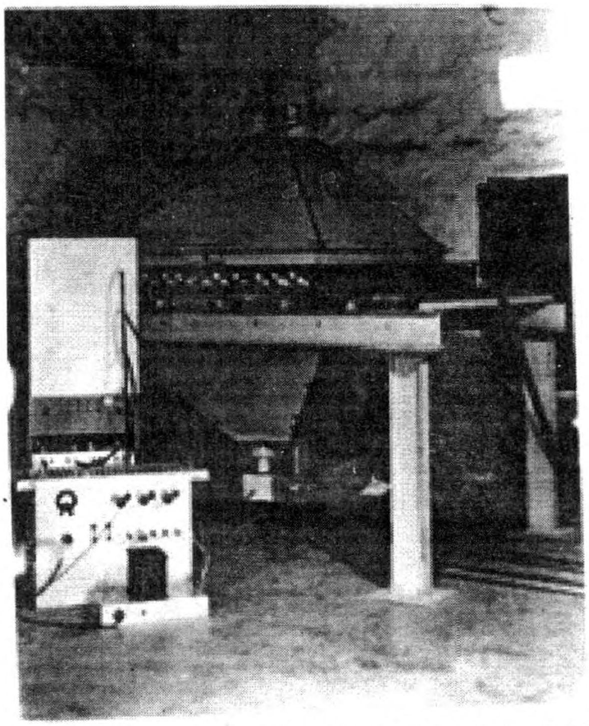

B.V. Sreekantan (1923– ), a student of Bhabha, was instrumental in setting up the very first experiments in the Kolar gold mines. He later headed TIFR from 1975 to 1987.

A good part of the electronics equipment was acquired at throwaway prices from the Chor Bazar, Bombay's notorious flea market, where a lot of military surplus war had ended up after the War. Sreekantan and his collaborators soon found that the flux of muons reduced dramatically as the depth increased and was likely to be completely shielded at depths of around 2 Km. However, at those depths, his Geiger counters began to tick again. Sreekantan reported this to Bhabha, who immediately guessed that this must be due to radioactivity in the rocks at this level. We may recall that in 1914, Watson and his team had not found any radioactivity in the surface rocks at Kolar. Sreekantan was then able to prove the correctness of Bhabha's hypothesis by putting lead shielding around his equipment, which stopped the alpha radiation from the radioactive rocks, but let the muons through. In fact, there are traces of radioactive Thorium-232 in the Kolar rock, especially at great depths.

Muon flux measurements won Sreekantan his Ph.D., but he and his team had uncovered something even more exciting. In 1955, the neutrino had been discovered, and its interaction cross-sections with matter matched the inverse beta decay predictions made with the Fermi theory of weak interactions. In 1957, Moisey A. Markov, at Moscow, realised that the ideal place to look for neutrinos would be deep underground, since most of the noise from cosmic rays would be shielded out and only the neutrinos could penetrate that far. Markov did put a couple of his students to this job, but it never really took off till the Baksan observatory was initiated in the Caucasus mountains in 1967. Instead, Bruno Pontecorvo's suggestion of studying high fluxes of neutrinos at an accelerator gained favour, and ultimately led to the experiments which proved the separate existence of the electron neutrino and the muon neutrino (Lederman, Schwartz and Steinberger, 1962). However, Bhabha, Sreekantan and their group were quick to take up Markov's suggestion, realising that the Kolar mines at depths greater than 2 Km were the perfect setting envisaged by the Russian Academician. Sreekantan had now been joined by a new student, V.S. Narasimham. A collaboration was also set up with S. Miyake of Osaka

University. First, some of the collaboration members–Narasimhan, Ramana Murthy and Miyake –made careful measurements of the muon flux to determine the correct depth at which to place the neutrino detector. They found that at a depth of 2.7 Km, they did not detect a single muon in two months over an area of roughly three square metres. When contrasted with the surface flux, which would be like a *million* muons per minute over the same area, it was clear that the shielding was really good. The actual experiment was, however, done at a depth of 2.3 Km in the Heathcote shaft of the Champion Reefs mine, mainly for logistic reasons.

The cross section of neutrinos with matter is so small that it would have required a detector weighing several kilotons to see neutrinos directly at the Kolar mines, and this was definitely outside the logistic and financial power of TIFR. However, the Kolar team came up with an ingenious solution. The miles of *rock* surrounding the mineshafts were as good as any detector, since neutrinos could easily interact with the nuclei in the rock through inverse beta decay, producing muons. And the Kolar experiments were perfectly geared to detect muons. It would be easy to distinguish these secondary muons from cosmic ray muons, because the latter would be moving vertically, whereas these would come in laterally. And so, in 1965, the Kolar experiment was the first in the world to detect the atmospheric neutrinos. The paper published in *Physics Letters* was authored by C.V. Achar, M.G.K. Menon, V.S. Narasimham, P.V.Ramana Murthy and B.V. Sreekantan, representing TIFR, by K. Hinotani and S. Miyake, representing the University of Osaka, and D.R. Creed, J.L. Osborne, J.B.M. Pattison and A.W. Wolfendale, representing the University of Durham.

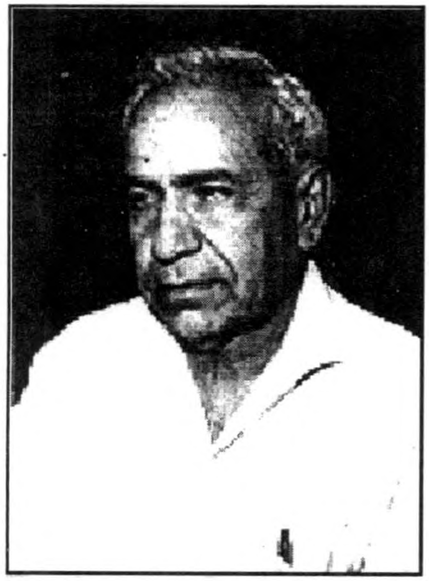


The main experimental setup at the Kolar Gold Fields, with alternate layers of scintillator material and GM counters, ina huge inverted tetrahedron, in proximity with photomultiplier tubes. It was with this setup that the first atmospheric neutrinos were observed.

In the 1970s and 1980s, the Kolar experiments were revamped to look for proton decay, then an important prediction of Grand Unified Theories (GUTs). This study continued, with negative results, until the mines were closed down in 2001. But all this belongs to a different era and will not be taken up in this article.

The story of Kolar will not be complete without a mention of the mysterious 'Kolar events', which seem to have been due to the passage of weakly-interacting particles of masses around a few GeV through the detectors. First reported in 1975, these have remained a mystery all through the past four decades. There have been recent speculations that these are due to the particles which make up the dark matter component of the Universe. If this is verified in any of the current dark matter detection experiments, then the first dark matter detection will have taken place at Kolar.

### P.S. Gill and the Aligarh Group



P.S. Gill (1911–2002), came back to India in 1940 and initiated cosmic ray studies at Lahore and later, at Aligarh Muslim University. In 1963, he became Director of the Central Scientific Instruments Organisation (CSIO), Chandigarh.

Bose, Bhabha and Sarabhai were not the only pioneers in particle physics in India. A less-known name, but no less a pioneer, was Piara Singh Gill (1911–2002) usually abbreviated as P.S. Gill. Unlike the others, Gill came from a poor farming background, where, as a child in the Hoshiarpur district of Punjab, he had to walk five kilometers and back every day to attend school. Emigrating to the New World after leaving school (1929), his first stint was as a taxi driver in Panama City. Soon, however, the determined youth was able to get a Bachelor's degree from the University of Southern California, to finance which he did all kinds of odd jobs, including scrubbing floors, washing dishes and picking fruits. He then moved to the University of Chicago (1936), where he was able to do his Ph.D. under the supervision of none other than Sir Arthur H. Compton, the 1927 Nobel Laureate and discoverer of the famous Compton effect, which is in every textbook. Working with Compton, Gill established the well-known latitude effect in cosmic ray distributions, thereby proving conclusively that the bulk of the primaries come from the solar wind. In 1939, he presented a paper on cosmic ray distributions which was later hailed as the first indication of the spin of the pion, later established with much effort from proton-proton scattering. This won him his Ph.D. in 1940 and he could have stayed on at Chicago as a research assistant, but Gill was made of sterner stuff. He applied and secured a one year travelling studentship and came back to India, where, at that time, there were practically no facilities for the kind of research he had been pursuing. The generosity of Compton allowed him to bring back with him the expensive equipment he had been using at Chicago. Gill found himself a job as a Lecturer at the Forman Christian College in Lahore, where he spent the war years, setting up high altitude cosmic ray studies, first at

Gulmarg in Kashmir and then, as the Allied victory became more certain, with the help of British war planes. It is significant that during the war years, no fewer than four stalwarts were working on cosmic ray physics in India–Bose, Bhabha, Sarabhai and Gill–but they all worked independently.

In 1946, Gill went on a lecture tour of the USA and Europe, where his work was very well received by senior scientists like Patrick Blackett, Pierre Auger, Viktor Hess (the discoverer of cosmic rays), and of course, his old colleagues at Chicago. The other important person to be impressed was Homi Bhabha, who persuaded Gill to leave Lahore and join the TIFR as Professor of Experimental Physics (1947). But the smart *sirdar* and the polished Parsee did not get along. Within a year, Gill resigned from TIFR and went away to the USA again. From there, in 1949, he was lured back to Aligarh Muslim University by the charismatic Vice Chancellor, Dr. Zakir Hussain (1897–1969, later to become the third President of India). At Aligarh, Gill built up his own cosmic ray group. Like the cosmic ray group at PRL, and the Bombay group under Peters, the Aligarh group's interest moved away from elementary particles per se and was more involved in nuclear reactions, geomagnetism and shower profiling.

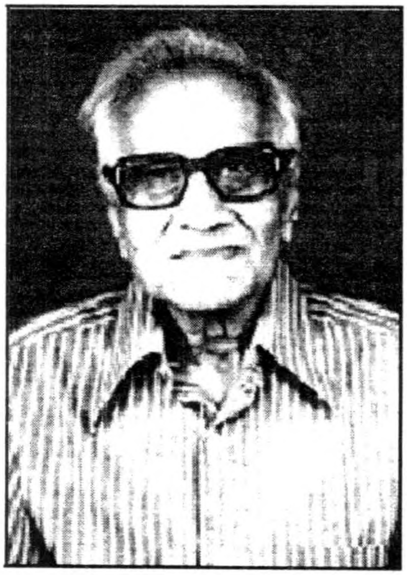
The lack of high quality scientific equipment in India has plagued experimental science in India since its inception. We have seen how it stunted the pioneering work of Bose and Choudhuri. It drove the mathematically-inclined Bhabha to design and fly his own balloons. It also affected P.S. Gill, who had carried his own equipment home from the USA. In 1963, therefore, he moved from Aligarh to become Director of the fairly new Central Scientific Instruments Organisation (CSIO) at Chandigarh, where he remained till retirement in 1971. Gill's dream was to see Indian experimental science free from the shackles of imported equipment. The CSIO has, it is true, patented a fair number of instruments, but the sad truth is that most good Indian laboratories still import most of their equipment.

After retirement, Piara Singh Gill tried his hand at entrepreneurship, setting up a company to manufacture magnetic heads for tape recorders. Eventually, however, he sold his business and went back to the USA to live with his daughter. There, he wrote his autobiography, where he raised many pertinent questions about the way Indian science has developed since independence. The ever-rebellious *sirdarji* was particularly caustic about scientific empire building. In 2002, at the age of 91, his own long innings came to a close. The questions raised by him remain.

### Particle Physics in Delhi University

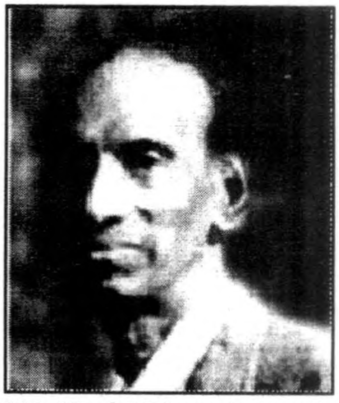
Sir Maurice Gwyer, a former Chief Justice of British India, took over as the Vice Chancellor of the University of Delhi in 1938. The University had been founded in 1922 with just three affiliated colleges (St. Stephen's, Hindu and Ramjas), and had been functioning largely as an examining body. Sir Maurice decided to open postgraduate departments in the University. To start the Physics Department, he recruited none other than D.S. Kothari, whom we have encountered earlier. Kothari had gone to Cambridge in 1934, on a strong recommendation from Meghnad Saha. He had done his Ph.D. with R.H. Fowler (adding to an illustrious list which included

Bhabha, Birkhoff, Chandrasekhar, Dirac, Eddington, Hartree, Mott and Lennard-Jones) and now was back to his position as 'demonstrator' in Allahabad University, at a monthly salary of Rs. 130 a month. From here, on another strong recommendation from his mentor Saha, he was appointed a Reader at the University of Delhi (DU for short) at the much more respectable salary of Rs. 350 a month. Around him, over the years, grew a galaxy of excellent teachers and researchers, including more students of Meghnad Saha, such as P.K. Kitchlew and R.C. Majumdar. In particular, the arrival of Majumdar sparked a flurry of theoretical particle and nuclear physics activity in Delhi University.



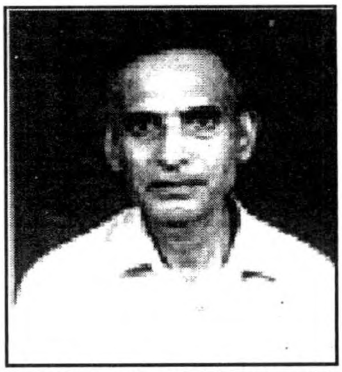
Ramesh C. Majumdar (1904–1995), with D.S. Kothari, was primarily responsible for the development of research in theoretical physics at DU.

The Kothari-Majumdar collaboration dates to 1939, when they published a letter in *Nature*, pointing out that the 'meson'–or pion as we would say today–should decay into electrons, but that those had not been seen. In fact, pions decay prominently to muons, and the reason is a standard textbook exercise today. At that time Majumdar was in the Bose Institute, then under its new Director, D.M. Bose. By 1942, however, we find Majumdar at Delhi, publishing calculations of meson-electron interactions with a young student called Suraj N. Gupta (b. 1924), who later became famous for his formulation of gauge field quantization. This collaboration continued even when Gupta went off to Cambridge and then to Dublin. However, the gauge field work was done on his own. In fact, Kothari and Majumdar were the two pillars on which the Department of Physics and Astronomy at the Delhi University grew up. Apart from their research, they trained generations of physicists, among whom was Jogesh C. Pati (b. 1937), the first proposer (with Abdus Salam) of grand unification and proton decay. Kothari, like Bhabha and Sarabhai, was called to serve the Government of India, first as Chief Scientific Adviser to the Ministry of Defence and then as Chairman of the University Grants Commission, while his alter ego, Majumdar, ran the Physics Department. In both of these positions Kothari left a rich legacy. Interestingly, though busy with policy making, he would continue to teach his classes, and was loved and respected by generations of his students–or so his obituaries say.



S.N. "*Dada*" Biswas is the only Indian to have actually discovered a particle (the hyperon). Two generations of particle physicists grew in Delhi under his mentoring.

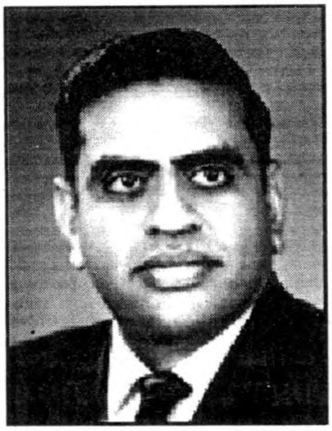
A less suave, but no less charismatic person in Delhi was Samarendra Nath Biswas (1926–2005), better known as S.N. Biswas, or, in his later years, as *Dada*. Educated at Calcutta, in the crucible which had already produced so many bright physicists, Biswas won a UNESCO fellowship to work in Australia in the late 1940s. Working at the University of Melbourne with a young Lecturer, Victor D. Hopper (1913–2005), Biswas identified a neutral baryon in cosmic rays, which decayed into a kaon, and was clearly what we today call a hyperon. Today we call it the Lambda baryon ($\Lambda^0$). This makes Biswas the only Indian to be actually credited with the discovery of an elementary particle. Homi Bhabha brought Biswas to TIFR in 1959, but the effervescent Bengali youth chafed under Bhabha's dominance. In 1964, he moved to Delhi, and remained there till his retirement. The story of particle physics in DU after the days of Kothari and Majumdar is largely the story of Biswas and his colleague, compatriot and rival, Ashoke Nath Mitra (b. 1929). A.N. Mitra was a student of R.C. Majumdar who went to Cornell University to do a second Ph.D. under Hans Bethe, though much of this work was done with Freeman Dyson. He later returned to India and eventually joined Delhi University in 1963. Both Biswas and Mitra did sterling work in quantum field theories, current algebra and S-matrix theories in the days before gauge theories began to rule the roost. The sheer range and scope of the research they undertook and the problems they attacked are awesome. They were the heart and soul of particle physics in Delhi until the 1990s. But all that belongs to a different story.


A.N. Mitra (b. 1929) was, with Biswas, a mainstay of particle theory in DU for several decades.

**Valediction : A Disclaimer and Some Reflections**

The author of this article is a physicist and not a professional historian of science. As such, there is practically no original research in this article. Most of the material has been gleaned from the internet and a few tidbits from hearsay and other people's reminiscences. Some of this information may, therefore, be inaccurate, though hopefully this will be a very small fraction. There is however, much to learn from this story, and some of those reflections and conclusions, as it strikes the author, are presented below. These opinions are entirely the author's own, and the reader is free to agree or disagree, in the true spirit of scientific discourse.

Particle physics has been the focus of this article, and we have looked at some of the highlights of particle physics research, as it developed in India from humble beginnings. Limitations of space and time make it impossible to cover all the work done in a comprehensive manner. Notable omissions include the theoretical work of Bhabha's first two students, D. Basu and S.K. Chakraborty, the careful experimental work done by M.S. Sinha and R.L. Bhattacharya, and the pioneering work of Alladi Ramakrishnan, another student of Bhabha, in applying stochastic methods to cosmic ray showers. Again, although particle physics and cosmic ray research grew out of nuclear physics, there was always a parallel growth of nuclear physics itself during the period of interest here. A separate article is required to do justice to the work of stalwarts like Meghnad Saha and his team who built the first Indian cyclotron (of whom B.D. Nagchaudhuri was the most prominent), to K.S. Krishnan, co-discoverer of the Raman effect, who tried to understand what we would today call the strong interactions, to the seminal work of S.N. Ghoshal which proved the existence of the compound nucleus, and, last, but not least, the work of P.L. Kapur, with Sir Rudolf Peierls on what we would today call narrow resonances in nuclear scattering. Scientists like Raman, Saha, Kothari and Majumdar were also amazingly versatile, and would work on topics as diverse as stellar atmospherics to improvement of GM counters to the study of band structure in solids.


Alladi K. Ramakrishnan (1923–2008) worked with Homi Bhabha on the treatment of a cosmic ray shower as a Markov chain.

This story draws to a close as it reaches into the mid-sixties. By then, particle physics research was well established in India, with several centres and satellite centres stretching to the four corners of the country. The first euphoria of Independence had worn off, with the new students coming in having been born in a free country. The colonial masters had been replaced by new satraps, and some of the rebels of the 1930s were now the kings of the castle. Overweening bureaucracy had begun to penetrate into everything, and the brain drain was truly on its way, sapping the strength of the fledgling science community which the early researchers had built up with so much hope and effort. Not till the 1990s would the Indian science community begin a slow recovery from these years of Government parsimony and neglect of academics–and that recovery is still far from complete today.

The importance of Cambridge University and the Cavendish Laboratory as a training ground for Indian physicists cannot be overemphasized. Except for S.N. Bose and P.S. Gill, almost every worker of note mentioned above was trained at Cambridge, or trained by Cambridge-trained people. In fact, the quality and impact of the research decreased in inverse proportion to the distance from Cambridge. Thus, the most impactful work in cosmic ray research is definitely that of Bhabha while he was part of the Cambridge group, and perhaps the most ignored work was that of Bose and Choudhuri in remote Calcutta during the War. People in those days were aware of it, and we repeatedly find them writing that they wanted to found institutions which would replicate the atmosphere of Cambridge and the Cavendish lab. This is a common thread which runs through the letters and speeches of everyone, from Maurice Gwyer to Bhabha, to Sarabhai, to Alladi Ramakrishnan. However, there is a fallacy in all this. *Cambridge grew*, and that too over centuries. The pioneers in India were therefore in the position of someone who plants a sapling and waters it furiously, hoping that it will grow overnight into a mighty banyan tree. This is not to detract from their efforts, which were truly Herculean, but just to set our expectations at the right level.

The other fact which repeatedly strikes one is that as soon as an Indian scientist became a savant of repute, he immediately quit science and became a manager. C.V. Raman, D.M. Bose, Meghnad Saha, Homi Bhabha, Vikram Sarabhai, D.S. Kothari, P.S. Gill and Alladi Ramakrishnan, who feature in this story, all fell prey to this impulse. The pattern has been replicated across subjects, and across the years. Of course, one can argue–and it has been so argued–that these brilliant minds had to face so many obstacles, that they decided to sacrifice their own scientific growth in order to ensure that the next generation of brilliant minds did not face the same obstacles. This is a fine and noble sentiment, but not necessarily the most practical one. For these brilliant minds were obviously doing fine, even with all the obstacles– else they would not have been the famous scientists they were. Their heroic sacrifice would have been worthwhile if there were other, equally brilliant minds among their successors, who could have reaped the advantage of their self-sacrifice. As it turned out, the next generation had no dearth of competent workers, but the spark of their *gurus* was missing. To some extent, the pioneers themselves were responsible for this, as they often showed themselves intolerant of disputation. In the wake of their empire-building came lobbying and the interference of politicians...

A third issue is the poor participation of women in this game, at least in India. Except Biva Choudhuri, no other woman even finds a mention. Again, this is a well-worked theme with feminist and liberal writers. It is also true that in the 1930s, women in India were still coming out of *purdah*. The story of the Marietta Blau shows that gender parity was still a far cry even in the West. In that sense, over the years, there has been an explosion of women in science in the world and in India, though, of course, the numbers are still small. Until women are free–and feel free–to pursue careers in science, the brains of one half of the population will remain largely untapped. One is reminded of a verse from the *Hitopadesha*, which reminds us that a chariot requires both its wheels to turn freely.

The final point–and this is perhaps the most important lesson to be learnt from this historical excursus–is that in the first part of the twentieth century, Indian scientists were doing research at the absolute cutting edge of contemporary knowledge. They fearlessly competed with giants, threw up new ideas without care of ridicule and were willing to do the most difficult experiments with the most primitive of equipment. The number of original scientific ideas which flowed out of Indian minds has not been replicated since. After independence, we have founded many new institutions, with excellent teaching–the IITs come to mind–and imported supposedly healthy academic practices like peer review and tenure track positions to ensure that our burgeoning science community stays on track. And that is precisely what has happened–we have stayed on the track, some going fast and some going slow–but other people have been laying the tracks. In the 1930s and 1940s, there were no tracks, so Indians laid their own. It is perhaps this spirit of intrepidity that we need to grow again, if the dreams of those pioneers are ever to be fulfilled.

## Endnotes

[1] B.B. Ray is practically a forgotten figure today, even in his own Department. As a student of the Department in the 1980's, all that the author knew of him was the mnemonic "B.B. Roy of Great Britain, Very Good Wife", which was used to remember the colour code of resistors (Black, Brown, Red, etc.). And yet Ray was a stellar figure in those days, having collaborated with Nobel Laureates like Bohr and Siegbahn, and being a prolific author in the field of X-ray spectroscopy. Sic transit gloria mundi.

[2] The elder and the younger Bose were later to fall out over the issue of who was invited to the Volta Conference at Lake Como (1927), where D.M. Bose and M.N. Saha attended. S.N. Bose always thought the invitation had been for him. However, he did not open his mouth till 1964, when he was 70 and D.M. Bose was 79, and the Volta Conference was a distant memory.

[3] Born, a Jew by birth, was then fleeing from the anti-Semitic Nazi regime in Germany. He came to Bangalore at the invitation of C.V. Raman, and he and his wife liked the place so much that they wanted to stay there permanently. Unfortunately, Born's candidature for a Professorial Chair in Theoretical Physics was shot down in the IISc faculty by a long-forgotten electrical engineer named William Aston, who forcefully argued that the IISc had no need to create a chair for a 'second-rate foreigner, who could not find a place in his own country'. Even Meghnad Saha, then in the IISc Review Committee, roundly criticized Raman's efforts to hire a mathematical physicist in an Institute which was supposed to be devoted to industrial research. Sadly, the 'second-rate foreigner' had to settle for the Tait Professorship at Edinburgh, where he succeeded C.G. Darwin, and eventually gained the Nobel Prize.

[4] Already there had been attempts at higher order calculations in QED and those had led to infinities which refused to go away. Not until renormalization was invented in the 1940s did this problem get resolved.

[5] Before the wholesale migration of European savants to the New World, the Physical Review was not all that prestigious a journal.

[6] They did, however, make him a Fellow of the Royal Society in 1941. Dirac was the proposer.

[7] This was estimated by Bose and Choudhuri at 76–135 MeV/$c^2$ in 1941, and then, after incorporating corrections (one suggested by Bhabha) as a mean value of 96.5 MeV. It is possible, therefore, that many of the tracks seen by Bose and Choudhuri were due to the muon (mass 105 MeV/$c^2$), which had been discovered in 1937, but the large-end results must have been due to pions (mass 140 MeV/$c^2$). With the resolution available using halftone plates, there was no way of distinguishing the two.

[8] Their team included Hugh Muirhead, who is better remembered as the author of a classic textbook on particle physics.

[9] Robert A. Millikan, the American Nobel Laureate, had actually come to India in the 1930's to take advantage of this.

[10] One in Nature, and two in the Physical Review.

Dr. Sreerup Raychaudhuri did his M.Sc. and Ph.D. from the Department of Physics, CU. He was a faculty member of IIT Kanpur from 1999 to 2007, and since then, a Professor in the Department of Theoretical Physics, TIFR. He is a particle physicist by profession, and his major areas of interest are the electroweak interactions, supersymmetric models, and low-scale quantum gravity. Most of his research is centred around predicting experimental signatures for such theories, especially in the context of high-energy colliding-beam machines.

# Reminiscences

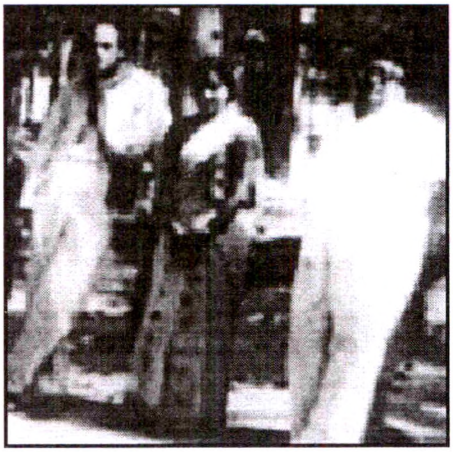
**Purnima Sinha**

Around the middle of 1951 I started working on my Ph.D. with Prof. S.N. Bose at the Khaira Laboratory in Kolkata. He advised me to carry out an investigation on the structure of clay from various parts of India. He suggested that I could use techniques of thermal and chemical analysis along with X-ray scattering and also suggested that I fabricate my own X-ray tube of the Coolidge kind so that the parts could be dismantled and put together at will.

At that time about ten of us were involved in experimental research at the Khaira laboratory. Each of us used to fabricate his or her own instrument according to individual need. This was an unwritten rule in our laboratory. The more experienced research students used to initiate newer students in this mode of doing research and Prof. Bose would routinely keep track of the problems we faced in the lab as well as our progress. There was constructive cooperation between fellow students and people working in related departments. We all enjoyed the excitement of doing science in this manner. Because of the desire to hasten the pace of doing research there has been a trend towards buying easily available expensive imported equipment. It would have perhaps been possible to develop a much more self sufficient and confident scientific culture in the applied sciences in our country–in spite of the slower pace–if the ideal set by Bose had been followed.

The high voltage transformer used for our X-ray equipment was fabricated in the applied physics department of our university. We had put together our X-ray equipment from the World War-II surplus gathered in the lane behind Dr. Bidhan Roy's house. The rest of the parts were put together at the workshop in our department. Our efforts in the X-ray laboratory finally led to a complete classification of about fifty clay samples into categories like Kaolinite, Montmorillonite, Illite, Vermiculite, Chlorite and so on. The results of this investigation were put together in 1955. In 1956, Prof. Bose retired from Kolkata University and we did further detailed X-ray studies of the structural characteristics of these clay samples in collaboration with Prof. Kamalaksha Dasgupta.

Since that time years, many publications on X-ray analysis of clay samples have come out of the Geological Survey of India, Central Glass and Ceramic Research Institute, Indian Institute of Technology and many other institutes. Few will realise that it was S.N. Bose, one of India's finest theoretical physicists, who first initiated research in X-ray based structural analysis of clay samples from different parts of this country!



*The photograph shows Purnima Sinha (nèe Sengupta) with S.N. Bose and P.A.M. Dirac during Dirac's visit to Bose's laboratory in the mid 1950's when Purnima was doing her Ph.D. research with Bose.*

(Reprinted from: *Like Mother, Like Daughter: Purnima Sinha and Supurna Sinha*, Lilavathi's Daughters, *p. 305*, with kind permission from the Indian Academy of Sciences.)

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Purnima Sinha (nèe Sengupta) was the first lady Ph.D. in Physics from Calcutta University. After her Ph.D. she worked in Biophysics at Stanford University, on the Origin of Life during the year 1963–1964. This work was at the interface of biology and physics, studying structures involving clay and bases appearing in the DNA double helix. She then worked in the Geological Survey of India, Bose Institute, and Central Glass and Ceramics Research Institute. After retirement, she continued to popularize science. She passed away in 2015.

# Purnangshu Kumar Roy: Protégé and Friend of S.N. Bose

**Charles Wesley Ervin**

## Background and Schooling

Dr. P.K. Roy was born in Meerut, where his father, Raj Kishore Roy, worked in the Defense Accounts Department of the Government of India. He was the youngest of eight siblings, five brothers and three sisters. After retiring from service in 1925, his father moved the family back to Calcutta and built a large house at 13, Nanda Kumar Chaudhury Lane, near the corner of Vivekananda Road and Cornwallis Street. Purnangshu–who went by the nickname "Nitai"–went to school at nearby Scottish Church School and then to college at Scottish Church College, where he excelled in mathematics. The Principal sang his praises: "He was one of the most brilliant students of his time in College, obtaining uniformly high marks in his class examinations."

## Calcutta University

Purnangshu continued his mathematics education in Calcutta University's College of Science and Technology and taught at the Vidyasagar College. In 1947 he passed the M.Sc. exam in Applied Mathematics and the following year joined the research laboratory that S.N. Bose had just established. Bose recognized Purnangshu's potential and nurtured him as a protégé. The two became close on a personal level, too. Purnangshu frequently visited the Bose residence at 22, Ishwar Mill Lane.

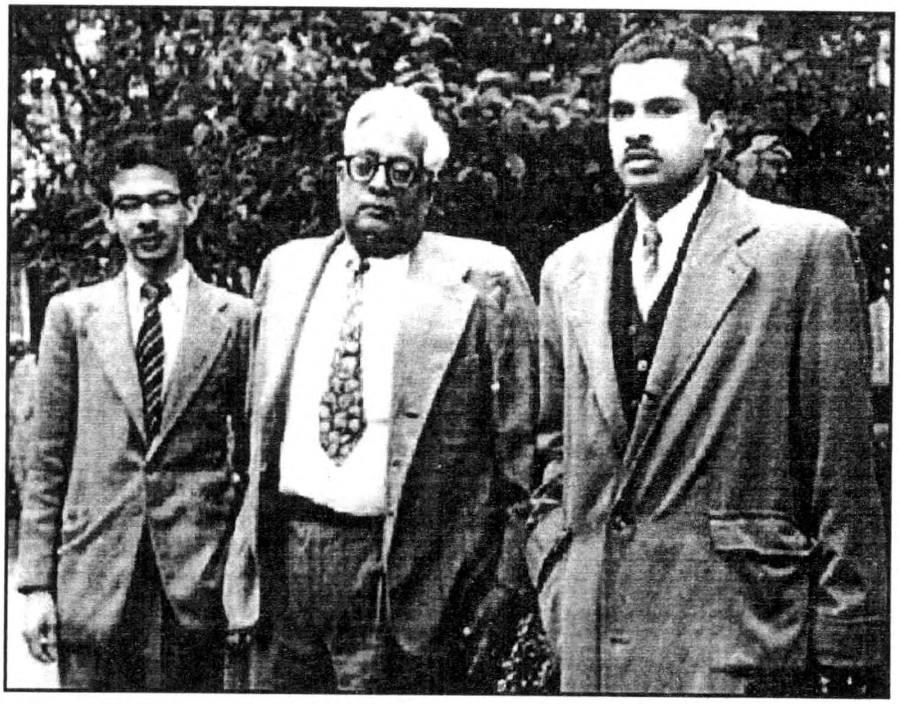
## Imperial College, London

In 1957 Purnangshu, with Bose's backing, went to Imperial College in London to get his Ph.D. in mathematical particle physics. The future Nobel Laureate, Abdus Salam, had just accepted the chair in theoretical physics in the Mathematics Department at Imperial College. His colleague and best friend, P.T. Mathews, joined him. Mathews and Salam had been working on the complex problem of renormalization of meson interactions since 1950. Purnangshu decided to focus his Ph.D. research on the properties of $K^-$-mesons, particles with zero spin with unknown intrinsic parity.

Purnangshu studied the groundbreaking work of Arthur Wightman, who developed an axiomatic approach to quantum field theory in which physical results, such as the parity-charge-time symmetry and the connection between spin and statistics, became mathematical theorems [1]. Purnangshu published two research papers on meson-nucleon interaction and dispersion relations while he was still a graduate student [2]. In 1959 he was awarded a Ph.D. for his work on Fundamental Particles: Mesons and Paired Nucleon.

## Career in the Physics Faculty of Calcutta University

Upon his return Purnangshu became a Senior Scientist in the Department of Pure Physics, University College of Science. Bose secured a fellowship that enabled him to continue his research in relativistic dispersion relations [3]. In 1964 Purnangshu was appointed a Reader in Pure Physics. In a recent email Partha Ghose, who was then a Junior Scientist in the department, recalls, "I had the privilege to learn much physics directly from him. He was a very friendly and helpful person." Purnangshu could lace his logic with wit. Speaking at a symposium on particle physics, he concluded [4], "the boundary between the two types of strongly interacting particles will tend to collapse, not because the theoretical physicists promise a successful solution but because the familiar particles have already started getting stranger and stranger."



Purnangshu Kumar Roy (right) with S.N. Bose and fellow graduate student Biren Datta (left) in London. Photo courtesy Anjana Srivastava.

## A Well-Rounded Man

In 1963 Purnangshu married his niece, Gopa ("Uma"). They had a daughter, Anjana ("Munia"), who studied mathematics before going on to get an MBA from Mumbai, where she lives with her husband and daughter.

Purnangshu had many interests outside academia. When he was still in his teens, he was politicized by the Quit India struggle and became a Marxist. He and his sister, Suprava, joine the small party of Trotskyists, who were opposed to the Stalinist politics of the official Communist

Party. Suprava was the fiery militant activist, Purnangshu the cool, cerebral Marxist theoretician who mainly wrote articles. He learned to speak and write Russian and was well versed in classical English and Bengali literature. He could quote passages from Shakespeare from memory. Music was another passion. He was also a formidable bridge player.

## Handicaps

When he was in his thirties Purnangshu was diagnosed with ankylosing spondylitis, a debilitating form of progressive arthritis in the spine. By the 'sixties he could get up and walk only with difficulty. But he never let his suffering stop him from teaching and mentoring the physics students. Ironically, Abdus Salam also developed a degenerative neurological disease that made his later life difficult. In the late 1960s Purnangshu devoted time to caring for the family of his late elder brother, Dr. Himangshu Roy, a noted cardiologist.

## A Final Masterpiece

In 1974, on the fiftieth anniversary of the publication of what became known as the Bose-Einstein Statistics, Purnangshu was asked to write an article that would explain to the general public–without using any mathematical equations–the significance of what Bose had done. The result is truly a masterpiece of exposition and clarity [5].

That proved to be his final scientific work. By late 1974 he was suffering from fever and jaundice. The doctors couldn't diagnose the condition. He became bedridden. In June, 1975 Dr. Anil Sensharma, a close relative, had him admitted to the Eastern Command Military Hospital in Alipur. A cyst on his pancreas was removed. He started to recover, but in September his health deteriorated rapidly. Another surgery revealed metastatic cancer. Purnangshu died at midnight on September 19, 1975 at age 50 with his wife at his side.

The Bengali weekly, *Desh*, published an obituary, citing his accomplishments in theoretical physics and praising his 1974 article on Bose as "on the one hand fluid in language, beautifully clear and on the other hand masterly in the exposition of the Bose statistics." The tribute aptly concluded [6], "Dr Roy was a 'thorough' man, as much in science as in other areas he had interests in–literature, music, sports and 'addas'. He charmed his students, professors, anybody and everybody he met."

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[6] *Desh*, October 18, 1975.

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Charles Wesley Ervin studied physics at the University of Chicago as an undergraduate and then did his PhD at Chicago in South Asian Studies. He interviewed P.K. Roy in 1974 during his field research in India. He subsequently pursued a career in Information Design, specializing in the visualization of complex data. Email: wes_ervin@bellsouth.net

# Through a Kaleidoscope

**Indrani Bose**
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I spent some of the happiest years of my life in the Physics Department of Calcutta University, first as an M.Sc. student (1973–1976) and then as a pre-doctoral research scholar (1976–1981). Our M.Sc. class, to borrow the language of social networks, was highly connected with little opportunity for isolated cluster formation. The spirit of universal camaraderie made us a united 'whole', rather than splintered groups. We had a galaxy of interesting characters in class and I will mention only a few of them. Sabyasachi Chatterjee came from St. Xavier's College and announced on the very first day of our acquaintance that he was the President of the Mad Peoples' Association in his college. Himansu Kundu used to disappear for days on solo journeys to remote, almost inaccessible places and come back with tales of high adventure and fascinating encounters. Santwana Roy Choudhury was spontaneity personified and peppered her conversations with the limericks of Sukumar Ray. With such classmates around, life could never be dull!

We had a very good relationship with our professors. Most of them were informal and easily accessible. The topics taught covered an exhaustive syllabus which most of our teachers adhered to. Very few professors gave us home assignments or problem sheets to work on. Some years later, when Prof. Chanchal Kumar Majumdar joined the Physics Department as the Palit Professor, he initiated the practice of giving problem sheets for each of the courses he taught. One course in which we got a problem sheet was that on Mathematical Methods. Our original plan was to solve the problems collectively sitting by the side of the Ganges in Falta. Ultimately, the problems were solved in more prosaic places like the Departmental Library and the Science College Canteen. We often held sessions in groups discussing the various concepts and theories we learnt at class and these impromptu sessions helped in enhancing our understanding of Physics. In our times, there was neither internet nor photocopy machines and our only sources of information were the books in the library. The Librarian Madhubabu and the staff Naran-da and Shyam-da helped us in all possible ways. Our study material was often based on handwritten notes with the contents gleaned from more than one reference book. The very act of preparing the notes constituted part of the learning process. During breaks, Naran-da would regale us with anecdotes on past students some of whom were established academicians by that time. We kept the memories of earlier students alive through bits and pieces of chance information on their progress through life, a fine example of historical continuity.

I had Nuclear Physics as my Special Paper and I treasure the memory of our practical classes under the supervision of Prof. Asim Kumar Ganguly. On the very first day, Prof. Ganguly told us that he would give each pair of students (the so-called 'partners' who would jointly carry out the experiments) an instrument or device which was malfunctioning due to some defect or other. The task of each team would be to identify the defect in the device assigned to it, rectify the defect and make the device functional. In this whole process, the students would be totally on their own. My practical partner was Anuradha Basu (now De) and we got a defective power supply to try our skills on. We had little practical knowledge of electrical circuits and in the next few weeks we would often visit the library of the Saha Institute of Nuclear Physics (SINP), which was then located in the Science College Campus, and pore over books on electrical circuits to learn about the different components of a power supply as well as its principle of operation. After several days of hard labour and inspired guesses, we triumphantly told Prof. Ganguly that we had rectified the defect in the power supply. Prof. Ganguly said that he would test it to check whether it was functioning properly. To our great disappointment, the test yielded a negative result and Prof. Ganguly explained to us where we had gone wrong. Though our enterprise ended in failure, we acquired much practical knowledge about electrical circuits. While we were carrying out the nuclear physics experiments in the laboratory located in the hostel building of SINP, we would sometimes find three students, Jayanta Kumar Bhattacharjee, Partha Mitra and Rupayan Bhattacharya, one batch senior to us, visiting Prof. Asim Ganguly to work on some nuclear physics problems. This was when their final M.Sc. exams were already over. The three students were inseparable friends and formed a legendary trio famous for their academic brilliance. Our impression was that they had no life beyond academics. During one of our 'adda' sessions, Sabyasachi came back running from the canteen to inform us excitedly that JKB was quoting cricket statistics like an expert cricket commentator. I had gone with my parents to watch a Russian production of the Hamlet and was astounded to see the trio in the audience. Of course, the very next day I shared my knowledge with my classmates. It is a different story altogether that in later years some of us got to know Jayanta, Partha and Rupayan well as friends. Coming back to nuclear physics experiments, Anuradha and I did the unthinkable by working on a very sophisticated fast-slow coincidence circuit, designed by Prof. Ganguly, after our exams were over. The experience constituted our first involvement with an actual research project. During our M.Sc. years, an international conference was held in the SINP auditorium on the Fifty Years of Bose Statistics. Prof. S.N. Bose was present during the conference and we attended some of the lectures due to our general fascination with physics and physicists.

After the completion of our M.Sc. course in 1976, I continued in the Physics Department as a research student of Prof. Chanchal Kumar Majumdar, popularly known as CKM. I had initially planned to go abroad for my doctoral studies but some of my M.Sc. professors advised me to work with Prof. Majumdar. They expressed the opinion that I should certainly avail of the opportunity to work under the supervision of a brilliant scientist like Prof. Majumdar. Prof. Majumdar had left the Tata Institute of Fundamental Research (TIFR) the previous year and joined the Physics Department of Calcutta University as the Palit Professor. He was an outstanding physicist with a brilliant academic career and vast erudition. His pioneering research contributions brought him fame and recognition both nationally and internationally. He was an ex-student of the Physics Department and Naranda who had a special fondness for him related a number of stories about CKM's student days. In my opinion, Prof. Majumdar's joining the Physics Department was a landmark event in the history of the Department. He came with a missionary zeal to raise the standards of physics education and research in the Department to international levels. There were times when he was simultaneously teaching courses on statistical mechanics, quantum mechanics, mathematical methods and condensed matter physics. Apart from giving problem sheets, he used to call students at random to the board to work out problems.There are hilarious tales of how the students tackled the joint menace of CKM and the blackboard. Students would find appropriate hiding places in the Department and take refuge there (one of the places was Banibabu's room) before CKM's class was due to start. The most imaginative of the hiding places would, however, yield to the ingenuity of Babulal-da, a bearer attached to the Palit Laboratory, who would accost the students with the cryptic message "Sir is calling you." Prof. Majumdar would often forget about time while teaching, specially, if his was the last class. Sometimes Babulal-da would bring in tea for both him and the students. Prof. Majumdar once showed me a letter written to him by Sumit Ranjan Das, his M.Sc. student, who had joined the Ph.D. programme of a reputed university in USA. In the letter Sumit had said that after attending Prof. Majumdar's classes it was not at all difficult for him to cope with the coursework at the US University.

After he joined the Physics Department, Prof. Majumdar initiated a Wednesday Lecture Series in which he gave comprehensive lectures on many body theory, statistical physics, superconductivity and magnetism. This was like an extended coursework and many scientists from all over Calcutta attended the lectures in a regular manner. Prof. Majumdar would carry out difficult mathematical derivations (e.g., the determination of the exact partition function of the Ising model in two dimensions) on the board without consulting notes and without making a single mistake. The lectures continued for a few years. He would also give special lectures introducing new research topics. I first heard of the percolation model from one such lecture. The lectures provided us with a glimpse of the then emerging areas of research. The computational facilities available in Kolkata got a big boost with the installation of the Burroughs computer at the Regional Computer Centre of Jadavpur University. Though my thesis work did not require computations, Prof. Majumdar insisted that I learn computer programming and run the programmes (punched cards) on the Burroughs computer. He gave me a huge programme on the determination of the roots of a polynomial by Müller's method which he had used in TIFR. My task was to decipher the programme and test it on the computer. Bikas Chakraborty was at that time a research student at SINP. He sometimes came to meet Prof. Majumdar for discussions on the research problems he was working on. My first acquaintance with Bikas was made when Prof. Majumdar introduced me to him and asked me to hand over the Müller's method programme to Bikas so that he could use it for one of his research problems. With active help from Prof. Majumdar, the Indian Physics Association (IPA) organized a set of lectures on Fortran programming in the Physics Department. The course was taken by Dr. Subrata Ray and many of us, including my friends Sujit Saha and Santwana Roy Choudhury from SINP, attended the lectures. Subrata-da was a brilliant teacher and under his tutelage some of us developed an addiction to writing computer programmes in Fortran. One has to remember that in those days familiarity with a programming language was not as universal as it is now. I used to visit my friends at SINP almost everyday (SINP was still located in the Science College campus) to discuss the various algorithms of numerical analysis. I was asked by Prof. Majumdar to teach Fortran programming informally to one batch of M.Sc. students. I had a unique experience as a first-time teacher 'though how much the students learnt from my lectures is a matter of conjecture. It was through this class that I became acquainted with several of my juniors like Subinay Dasgupta and Purusattam Ray.

The first research problem assigned to me by Prof. Majumdar was related to the three-magnon bound state. He showed me a horrendous looking integral equation which he had derived while he was at TIFR. He said that we would have to invent a method for solving the integral equation. In the process we would solve a three-body eigenvalue problem exactly and analytically, a rare feat in theoretical physics. After several hundred pages of calculation, the exact, analytic solution was finally arrived at. Prof. Majumdar was enormously happy with the solution and we published a paper in the Journal of Mathematical Physics. In the course of the calculation I was stuck at one point due to the appearance of unphysical imaginary quantities. When he heard about the problem, he told me to go to the library and look up a paper by C.N. Yang. He did not say anything else. I looked at the paper and got the clue. I was astounded by Prof. Majumdar's phenomenal memory in quoting the exact volume and page numbers of the paper. During my research I cooked up a spin Hamiltonian for which the well-known Néel states turned out to be the exact eigenstates. When I showed my calculation to Prof. Majumdar, he said that proving an eigenstate to be the exact ground state was a more difficult problem. As usual he offered some clues but was skeptical whether any of these would work. While thinking about the problem, I came up with a surprisingly simple argument as to why the exact eigenstate is also the exact ground state of the special Hamiltonian. I made a trip to SINP to try out my line of reasoning on my friends Santwana and Sujit and get their response. They could not find any loopholes in my argument. I gathered courage, went to Prof. Majumdar and explained what I had done. He listened to me twice and then pronounced "You are perfectly right." That was certainly one of the happiest moments of my life. Prof. Majumdar supervised the research studies of several other students in the Physics Department before he left the Department to join the Indian Association for the Cultivation of Science (IACS). He initiated experimental research activity in the later years to the surprise of all. It was difficult to imagine a great theoretical physicist like him busying himself with the designing of experiments. Prof. Majumdar was a staunch believer in the university system. He believed that the universities were the best places for promoting excellence in both teaching and research. It was a difficult decision for him to leave the Physics Department, CU and go to IACS.

There were quite a few active research groups in the Physics Department when I was a research student there. Prof. Dwijendra Lal Bhattacharya, Prof. Ramendra Nath Poddar, Prof. Pradip Narayan Ghosh and Prof. Manoranjan Saha had active research groups of their own. Some of Prof. Poddar's students like Subrata Pal , Santanu Datta (both were my M.Sc. class mates), Sunil Mukherjee and Bijayendra Palit were my close friends. I had a friendly relationship with the other research students also. Many of my friends were doing research at SINP and we would meet regularly in the open-air canteen adjacent to the SINP building. The research atmosphere in which we found ourselves was stimulating as well as intellectually satisfying. Abhijit Lahiri (Abhijit-da to all of us) took the initiative to start a History of Science Discussion Group which used to meet in the Biophysics seminar room of the Physics Department. The lectures and discussions were informal and thought-provoking. We had long hours of intense discussion on science, ethics and society. The proximity of SINP to the Physics Department gave the research students of the Department the opportunity to attend some of the post-M.Sc. courses at SINP. I attended Prof. Manoj Kumar Pal's course on statistical mechanics. Prof. Pal was an outstanding teacher and I feel fortunate that I got the opportunity to attend his lectures. I also got the permission to attend a French language course for beginners organized by SINP. Our teacher, Puskar Dasgupta, was simply excellent and we looked forward to attending his classes. Aloka-di (Aloka Poddar, a faculty at SINP) used to visit me at the Physics Department so that we could practice speaking in French. Unfortunately, the classes were discontinued after a year.

My formal association with the Physics Department, Calcutta Unversity came to an end in 1981 when I obtained my Ph.D. degree. I joined the Physics Department of Bose Institute as a faculty in 1987. Prof. K.C. Das, who was my M.Sc. teacher, invited me to take some classes in the Advanced Course in Condensed Matter Physics in the Physics Department of CU. This initiated another period of association with the Physics Department. Prof. Majumdar became the founder-Director of the SNBNCBS in 1987. Despite his busy work schedule, he took classes in the Advanced Condensed Matter Physics course regularly. Teaching was closest to his heart and he enjoyed talking to young students. At the time of his untimely death, he had just finished teaching his part of the course. He had left a message for the students at the corner of the blackboard, in Prof. K.C. Das' office, to contact him if they had any difficulty with the topics taught. Prof. Majumdar did not have a car, he used to carry a heavy portfolio bag and walk to Manicktala to board a bus to Salt Lake where his home was located. This sight made us feel humble and epitomized for us the saying "plain living and high thinking". I still visit the Physics Department for official work or to listen to lectures by visiting scientists. As I enter the first-floor corridor, I am flooded by happy memories. I can still identify a spot in the corridor, where Prof. Majumdar drew a map of Trieste, Italy in the dust covering the corridor, using the tip of his shoe. I will bring my reminiscences to an end now. The Physics Department, Calcutta University, has a special place in the hearts of its students. The Department inculcated in us a spirit of enquiry and liberal values. Our beloved Physics Department, we hope, will continue to fly its flag in full glory in the years to come.

Teaching and research on science subjects in the University of Calcutta were started by the Vice-Chancellor par excellence, Sir Asutosh. The Department of Physics, from the beginning, played a very important role, and has come through many ups and downs. This volume is an attempt to look back on the last century, the pioneering role of the teachers of the Department, and the history of science In British India in general.